JYU DISSERTATIONS 446

Irinja Lounassalo

Distinct Life Course Leisure-Time Physical Activity Trajectories and Related Health Behaviors

The Cardiovascular Risk in Young Finns Study

UNIVERSITY OF JYVÄSKYLÄ
FACULTY OF SPORT AND HEALTH SCIENCES

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“Physical activity is a complex behavior” – Carl Caspersen 1985 -
“Indeed.” – Irinja Lounassalo 2021 –

ABSTRACT

Lounassalo, Irinja
Distinct life course leisure-time physical activity trajectories and related health behaviors: The Cardiovascular Risk in Young Finns Study
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Physical activity (PA) has been suggested to play a role in the adoption of other health-enhancing behaviors. However, the evidence remains scarce. This dissertation research investigated the diverse pathways (i.e., trajectories) of leisure-time physical activity (LTPA) from childhood to middle age in the general population and the associations of these trajectories with other health-related behaviors (dietary behavior, screen and television time during leisure, binge drinking, smoking, and sleeping).

The doctoral dissertation yielded four original publications (I–IV). Study I systematically reviewed the articles identifying PA trajectories and related factors. Self-reported data from the Cardiovascular Risk in Young Finns Study were used in studies II-IV. Participants (N=3553, 51% women) were aged between 9 and 18 years at baseline (1980) and between 33 and 49 years at the last follow-up (2011). Trajectories were identified with latent profile analyses (II-IV). Models were adjusted for selected covariates.

The findings supported previous observations of the high prevalence and persistence of inactivity and low activity when compared to high or moderate activity in the general population (I-IV), especially in old age (I). Trajectories describing a decline in PA during childhood and adolescence were often reported whereas trajectories of increasing PA were observed in adults (I, III, IV). Men and women identified in the persistently active or increasingly active trajectories had a healthier diet (III, IV), lower smoking frequency, and fewer sleep difficulties (women only) when compared to their low-active or inactive peers (IV). Associations of screen and television viewing time with the LTPA trajectories were ambiguous (II, IV).

Being persistently active or succeeding in increasing one´s LTPA level during the life course may be important, not only owing to the benefits of PA for health, but also because it may relate to the adoption of other health behaviors, in particular switching to a healthier diet. Causality should be addressed in future intervention studies with objective measurements.

Keywords: physical activity, trajectory, longitudinal, diet, sedentary, sleep, smoking, binge drinking, life course

TIIVISTELMÄ (ABSTRACT IN FINNISH)

Lounassalo, Irinja
Liikunta-aktiivisuus elämänkulussa ja siihen yhteydessä olevat elintavat:
Lasten sepelvaltimotaudin riskitekijät -tutkimus
Jyväskylä: Jyväskylän yliopisto, 2021, 113 p.
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Liikunta-aktiivisuuden merkitystä terveellisten elintapojen omaksumisessa elämänkulun aikana on tutkittu rajallisesti. Tämän väitöskirjan tavoitteena oli tutkia väestöstä kehityspolkuanalyysillä identifioituja liikunta-aktiivisuuden alaryhmiä ja niiden yhteyttä muihin elintapoihin: ravintotottumuksiin, vapaa-ajan ruutuaikaan, unen laatuun ja määrään, tupakointiin ja alkoholinkäyttöön.

Tutkimus koostui osatutkimuksista I-IV. Systemaattinen kirjallisuuskatsaus (I) kokosi yhteen kehityspolkuanalyysillä liikunta-aktiivisuutta elinkaaren aikana tutkineet pitkittäistutkimukset. Osatutkimuksissa II-IV käytettiin Lasten sepelvaltimotaudin riskitekijät -pitkittäistutkimuksessa kyselylomakkein kerättyä aineistoa, josta identifioitiin kehityspolkuanalyysillä vapaa-ajan liikunta-aktiivisuuden alaryhmät lapsuudesta keski-ikään. Mukana oli kuusi ikäkohorttia (N=3553, 51% naisia), joita on tutkittu kahdeksan kertaa vuosien 1980 (tutkittavat 9-18 v.) ja 2011 (tutkittavat 33-49 v.) välillä.

Liikunnallisesti inaktiivinen elämäntyyli vaikutti pysyvämmältä kuin liikunnallisesti aktiivinen (I, III, IV). Suurin osa tutkittavista identifioitiin vähän liikkuvien tai inaktiivisten ryhmiin (I, III, IV) heidän osuutensa kasvaessa iän myötä (I). Liikunta-aktiivisuuden väheneminen alkoi usein jo kouluiässä (I). Aikuisilla havaittiin myös liikunta-aktiivisuuden lisääjien ryhmiä (I, III, IV). Epäterveellisiä elintapoja (epäterveellinen ravinto ja tupakointi molemmilla sukupuolilla ja univaikeudet naisilla) esiintyi todennäköisemmin vähän liikkuvilla tai inaktiivisilla kuin säännöllisesti lapsuudesta keski-ikään liikkuneilla tai liikunta-aktiivisuuttaan lisänneillä (III-IV). Ruutuajan ja televisioajan yhteydet liikunta-aktiivisuuteen olivat monitulkintaiset (II, IV).

Läpi elämän jatkuva liikunta-aktiivisuus tai sen lisääminen lapsuus- ja nuoruusvuosien jälkeen on aikuisuuden terveyskäyttäytymisen kannalta tärkeää: ei ainoastaan liikunnan terveyshyötyjen vuoksi, vaan myös muiden terveellisten elintapojen (etenkin terveellisten ravintotottumusten) omaksumisen vuoksi. Kausaalisuutta tulisi tutkia tarkemmin interventioissa käyttäen objektiivisia mittareita.

Asiasanat: liikunta, kasvukäyrä, kehityspolkuanalyysi, pitkittäistutkimus, ravinto, istuminen, ruutuaika, uni, tupakointi, alkoholinkäyttö, elinkaari

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However, I worked as a PE teacher for years and it was not until 2015 that I got back to YFS and began my dissertation. Mirja, I want to thank you for welcoming me back with open arms. You were a positively demanding, creative, and an attentive supervisor for me through this journey. No matter how busy you were, your door was always open – literally. In the moments of despair, you guided me and assured me that I was capable for mastering each task at hand. When I got exhausted, you reminded me to rest and spend time with my family. Thank you for caring and listening, Mirja. To my other supervisor, Senior Lecturer Sanna Palomäki: I want to thank you for reminding me not to linger on over minor details. Discussions with you helped me stay focused on the core of my research and your feedback assisted me in clarifying my thoughts. Your talent in giving comments precisely to the point is outstanding.

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In Jyväskylä on October 24, 2021
Irinja Lounassalo

LIST OF ORIGINAL PUBLICATIONS

This dissertation is based on the following original publications, which will be referred to by the following roman numbers (I-IV):

I. Lounassalo, I., Salin, K., Kankaanpää, A., Hirvensalo, M., Palomäki, S., Tolvanen, A., Yang, X., & Tammelin, T. H. (2019). Distinct trajectories of physical activity and related factors during the life course in the general population: a systematic review. *BMC Public Health*, 19:217. https://doi.org/10.1186/s12889-019-6513-y.

II. Yang, X., Lounassalo, I.*, Kankaanpää, A., Hirvensalo, M., Rovio, S., Tolvanen, A., Biddle, S. J. H., Helajärvi, H., Palomäki, S. H., Salin, K., Hutri-Kähönen, N., Raitakari, O. T., & Tammelin T. H. (2019). Associations between trajectories of leisure-time physical activity and television viewing time across adulthood: The Cardiovascular Risk in Young Finns Study. *Journal of Physical Activity and Health*, 16, 1078-1084. https://doi.org/10.1123/jpah.2018-0650.
**Yang and Lounassalo are both the first authors of this article and contributed equally to this work.*

III. Lounassalo, I., Hirvensalo, M., Kankaanpää, A., Tolvanen, A., Palomäki, S., Salin, K., Fogelholm, M., Yang, X., Pahkala, K., Rovio, S., Hutri-Kähönen, N., Raitakari, O. T., & Tammelin, T. H. (2019). Associations of leisure-time physical activity trajectories with fruit and vegetable consumption from childhood to adulthood: The Cardiovascular Risk in Young Finns Study. *International Journal of Environmental Research and Public Health*, 16(22): 4437. https://doi.org/10.3390/ijerph16224437.

IV. Lounassalo, I., Hirvensalo, M., Palomäki, S., Salin, K., Tolvanen, A., Pahkala, K., Rovio, S., Fogelholm, M., Yang, X., Hutri-Kähönen, N., Raitakari, O. T., & Tammelin, T. H. (2021). Life course leisure-time physical activity trajectories in relation to health-related behaviors in adulthood: The Cardiovascular Risk in Young Finns Study. *BMC Public Health*, 21:533. https://doi.org/10.1186/s12889-021-10554-w.

As the first author of the original publications (first authorship of Study II shared with Xiaolin Yang), I had the main responsibility in writing and conceptualizing the manuscripts while considering the comments of my supervisors and other co-authors. I drafted the study questions and designs in collaboration with my co-authors (I-IV). I performed the statistical analyses in collaboration with statisticians Asko Tolvanen (I, III, IV) and Anna Kankaanpää (I, III) except in Study II where they were the ones responsible. I searched the relevant literature with Kasper Salin for the systematic review (I) and used pre-existing longitudinal data gathered for the YFS in the studies II-IV. This research was funded by the Finnish Ministry of Education and Culture, the Juho Vainio Foundation, the Päivikki and Sakari Sohlberg Foundation and the Urheiluopistosäätiö.

FIGURES

TABLES

ABBREVIATIONS

ABIC	Adjusted Bayesian information criterion
AIC	Akaike's information criterion
BCH	Bolck-Croon-Hagenaars approach
BIC	Bayesian information criterion
BMI	Body mass index
FFQ	Food frequency questionnaire
FVC	Fruit and vegetable consumption
LTPA	Leisure-time physical activity
MAR	Missing at random
MET	Metabolic equivalent
MVPA	Moderate-to-vigorous physical activity
N / n	Number of cases
PA	Physical activity
PRISMA	Preferred reporting items for systematic reviews and meta-analyses
SES	Socioeconomic status
TV	Television viewing
YFS	Cardiovascular Risk in Young Finns Study

CONTENTS

1 INTRODUCTION

Recent research indicates that the benefits of physical activity (PA) for health and well-being are increasingly indisputable (Physical Activity Guidelines Advisory Committee, 2008, 2018). PA reduces the risk of several diseases and conditions, such as heart disease, stroke, hypertension, type 2 diabetes, injurious falls (among older people), dementia, depression, postpartum depression, excessive weight gain, and several cancers (Lee et al., 2012; Physical Activity Guidelines Advisory Committee, 2018; Raitakari et al., 1997; Sallis et al., 2016). Moreover, moderate-to-vigorous physical activity (MVPA) has been found to improve the quality of sleep (Kline et al., 2021), and regular PA to improve physical functioning and perceived quality of life (Physical Activity Guidelines Advisory Committee, 2018). Furthermore, higher amounts of PA at any intensity and less sedentary time are related to reduced risk for premature mortality (Ekelund et al., 2019; Lee et al., 2012). The benefits of PA can be achieved in various ways, and PA bouts of any length contribute to improvements in health (Physical Activity Guidelines Advisory Committee, 2018).

While the benefits of PA are widely recognized, 81% of school-going children and adolescents (Guthold et al., 2020) and 28% of adults (Guthold et al., 2018) do not meet the global PA recommendations set for their age groups (Bull et al., 2020). In Finland, corresponding proportions were 64% for children and adolescents in 2018 (Kämppi et al., 2018) and about 60% for men and 66% for women in 2017 (Borodulin & Wennman, 2019). This high prevalence of inactivity is a global public health concern (Hallal et al., 2012; Kohl et al., 2012) and imposes a substantial direct and indirect economic burden on health care (Ding et al., 2016; Physical Activity Guidelines Advisory Committee, 2018; Vasankari et al., 2018).

For these reasons, maintaining a physically active lifestyle or managing to switch from physical inactivity to activity is important. However, adopting a new behavioral pattern is not easy (Geller et al., 2017). Actions are needed on the individual, intrapersonal, environmental, regional and national policy, and global levels (Bauman et al., 2012). Relatively little is known about the changes - decreases or increases - that occur in PA behavior on the general population level or about the factors underlying these changes in individuals over the life course

(Corder et al., 2019). Thus, not only mean PA in the general population but also the different PA pathways between and within individuals need to be further studied in order to better understand the diverse development of PA during individuals' lives.

In addition to physical inactivity, other unhealthy behaviors present risk factors for health. Whereas physical inactivity, an unhealthy diet, smoking and the harmful use of alcohol have traditionally been seen as the four major health-debilitating behaviors (Noble et al., 2015), the current list also includes poor sleep quality and excessive sedentary time (Jike et al., 2018; Liu et al., 2017; Young et al., 2016). For example, an unhealthy diet, regular smoking, binge drinking (Lim et al., 2012), shortened (Liu et al., 2017) and prolonged sleep duration (Jike et al., 2018; Liu et al., 2017), insomnia (Kline et al., 2021; Sofi et al., 2014), and sedentary behavior (Chau et al., 2013; Young et al., 2016), such as prolonged television viewing (Sun et al., 2015) and total screen time (Grøntved et al., 2014), have all been found to be associated with a higher risk of non-communicable diseases and mortality. Non-communicable diseases are the cause of 73% of deaths worldwide (Roth et al., 2018) and unhealthy behaviors substantially increase the risk for these (Naghavi et al., 2017). Furthermore, combinations of unhealthy behaviors have found to be more detrimental to health than the same behaviors singly (Berrigan et al., 2003; Ding et al., 2015; Poortinga, 2007b). For example, a physically active lifestyle, with concurrent low sedentary time, non-smoking, moderate alcohol consumption, and a healthy diet, have been proposed to offer the best chance of avoiding obesity (Lahti-Koski et al., 2002), which accounted for four million deaths globally in 2015 (The GBD 2015 Obesity Collaborators, 2017).

Thus, adopting not only a physically active lifestyle but also an overall healthy lifestyle is important from the public health perspective. Previous cross-sectional studies have shown health-protective behaviors (PA, non-smoking, healthy diet and low alcohol consumption) to cluster (Noble et al., 2015) which raises the question of whether an overall positive health pattern exists, and if so, to what extent. Changing one behavior may lead to change in another behavior (Lippke et al., 2012). It has been proposed that PA, in particular, might play an important role in the adoption of other healthy behaviors (Blakely et al., 2004; Fleig et al., 2015; Kline et al., 2021; Pronk et al., 2004; Tucker & Reicks, 2002). However, previous research has mainly focused on the association of PA with a single health behavior. Longitudinal studies, with multiple measurement points during the life course, focusing on what developmental pathway (i.e., trajectory) of PA best facilitates the adoption by individuals of multiple healthy behaviors are lacking. It was the small number of studies in this research area that prompted this doctoral research project.

As occupations have become significantly less physically active (Church et al., 2011), PA during leisure has become important from the standpoint of having a physically active lifestyle. This dissertation mainly focuses on leisure-time physical activity (LTPA). Its objective was to investigate in greater depth not only individuals who maintain their habitual level of LTPA or inactivity, but also those who decrease or increase their level of LTPA from childhood to middle age.

The recent emergence of the statistical technique of trajectory modeling (Muthén & Muthén, 2017; Nagin, 2005) enabled the identification of homogeneous trajectory classes describing stability or change in LTPA in a heterogeneous study population. After identifying distinct LTPA trajectories, it was studied whether other selected health-related behaviors (dietary behavior, smoking, binge drinking, sleeping, and sedentary behavior) differed across the LTPA trajectories. It is essential to understand if potential lifelong inactivity might be reversed and whether an increase in the level of LTPA is also positively associated with favorable changes in other health behaviors. If so, this would have important implications for public health policymakers. It is also important to find out whether multiple health-compromising or health-enhancing behaviors accumulate over time in specific groups of people, and if so, at what age this process starts. It is important to start studying these associations between health behaviors already in childhood, as health behaviors during childhood and adolescence are major determinants of health behaviors in adulthood (Kelder et al., 1994; Malina, 2001b; Telama, 2009).

It was a privilege to be able to use 30-year follow-up data gathered for the Cardiovascular Risk in Young Finns Study (YFS). The YFS is an ongoing, longitudinal, population-based study consisting of randomly selected Finnish participants from six age cohorts aged 3-18 years at baseline in 1980 (N = 3596) (Raitakari et al., 2008). By the year 2011, eight follow-ups had been implemented. The YFS is an epidemiological study and thus fits in with the focus on behavioral epidemiology, specifically PA epidemiology (Pedišić et al., 2017), of this dissertation. The exceptional YFS data on the Finnish population enabled the identification of diverse longitudinal developmental trajectories of LTPA all the way from childhood into middle age and study of the associations between LTPA trajectories and selected health-related behaviors (dietary behavior, smoking, binge drinking, sleeping, and sedentary behavior). The identification of LTPA trajectory subgroups and examination of their related health behaviors is an important step in locating the key groups and life stages at which to target PA promotion and interventions and thereby contributing to improve public health and saving on health care costs.

2 REVIEW OF LITERATURE

2.1 Health-related behaviors

2.1.1 Physical activity

As physical activity (PA) is the primary focus of this dissertation, it is considered in more detail than the other health-related behaviors in this chapter.

2.1.1.1 Definition

PA is a complex and multidimensional behavior (Caspersen et al., 1985; Pettee Gabriel et al., 2012). In 1985, Caspersen with his colleagues defined PA as any bodily movement caused by skeletal muscles that results in increased energy expenditure (Caspersen et al., 1985). The definition was subsequently extended by adding that, as well as increased energy expenditure, PA results in various physiological attributes, including improved physical fitness (Pettee Gabriel et al., 2012). In the definition by Pettee Gabriel et al. (2012), physical fitness refers to flexibility, body composition, balance, muscular fitness, and cardiorespiratory fitness while energy expenditure refers to activity-related energy expenditure, thermogenesis, and basal (or resting) metabolic rate. However, this definition is being challenged, as recent findings indicate that not all the benefits of PA are easily represented by measures of energy expenditure or physical fitness. These benefits include increased quality of life, reduced fall risk among older adults, and an increase in social capital within a community (Troiano et al., 2012). In addition, PA during leisure and as a transportation activity has, unlike occupational PA, been found to be associated with mental health (White et al., 2017). PA also seems to be beneficial for sleep quality, feeling better, and performing daily tasks with fewer difficulties (Physical Activity Guidelines Advisory Committee, 2018).

PA can be characterized in diverse ways, such as its frequency, intensity, duration, and type. Intensity refers to the level of effort or physiological demand needed to perform the activity, and can be sedentary, light, moderate, or vigorous (Howley, 2001; Pettee Gabriel et al., 2012; Rhodes et al., 2017). Intensity is often defined as the level of energy expenditure of the PA in question and expressed as metabolic equivalents (METs) (Pedišić et al., 2017), that is, as the intensity value of a specific mode of PA in relation to the resting metabolic rate. One MET, defined as 1 kilocalorie per kilogram per hour, represents the caloric consumption of a person at complete rest. Thus, 2 METs describes the energy expenditure of an activity that is twice as intensive as the resting metabolic rate. Light PA is usually defined as 1.5-3 METs (e.g., walking slowly), moderate-intensity PA as 3-6 METs (e.g., walking briskly or cycling lightly), and vigorous-intensity PA as 6 METs or more (e.g., jogging or carrying heavy loads)(Pedišić et al., 2017). PA frequency refers to the number of times a person is active within a predetermined time frame and PA duration to the total time spent in performing the activity (Howley, 2001; Pettee Gabriel et al., 2012; Rhodes et al., 2017).

PA type can refer either to aerobic or anaerobic PA training, or to discretionary of PA, or to domain-specific PA (Rhodes et al., 2017; Troiano et al., 2012), where it is commonly divided into four domains: 1) LTPA, 2) occupational or school-related PA, 3) transport PA, and 4) household, domestic, or self-care PA (Pettee Gabriel et al., 2012) (Figure 1). Occupational PA is also sometimes referred to as work PA, that is, PA performed as part of paid or voluntary work (Bull et al., 2020). Transport PA is undertaken to get to places without using motorized vehicles (Bull et al., 2020). Household PA refers to domestic duties that include PA such as cleaning, caring for children, or gardening (Bull et al., 2020).

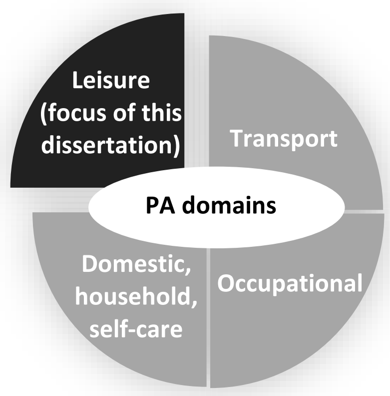


FIGURE 1 Domains of physical activity from Pettee Gabriel et al. (2012).

This study focused on the first of the four domains: LTPA (marked on a black background in Figure 1). LTPA is usually more planned and structured than, for example, occupational or domestic physical activities. LTPA refers to physical activities commonly based on personal interest and needs performed during free time (Howley, 2001). The World Health Organization defines LTPA as "physical activity performed by an individual that is not required as an essential activity of daily living and is performed at the discretion of the individual. Examples include sports participation, exercise conditioning or training and recreational activities such as going for a walk, dancing and gardening" (Bull et al., 2020). Sport participation is related to occupational PA among professional athletes, but is usually seen, along with participation in organized PA or exercising, as a subcategory of LTPA (Caspersen et al., 1985; Pettee Gabriel et al., 2012), as in the present study. Exercise is defined as planned and structured PA intended to improve or maintain some component of physical fitness or enjoyment (Caspersen et al., 1985) and sport as PA corresponding to any institutionalized and organized practice, governed by specific rules (Thivel et al., 2018). As with any other type of PA, LTPA results in energy expenditure according to its intensity, frequency, duration and type (Howley, 2001; Pettee Gabriel et al., 2012).

Of the different categorizations of PA, a simple threefold categorization comprising PA during sleeping, work, and leisure, was proposed by Caspersen et al. already in 1985 (Caspersen et al., 1985). The current, evolving area of research on 24-hour movement and non-movement behaviors has found this categorization useful, especially when using objective measures of PA. By using objective measures alongside diaries, 24-hour time-use behaviors can rather easily be divided into sleeping, sedentary activities, and physical activities (Norton et al., 2010; Tremblay et al., 2017). Although it was not possible to apply this approach in this dissertation owing to the absence of objective measurements of PA in the earlier follow-ups in the 1980s and 1990s, this threefold categorization of PA clearly has value in current PA research (Chastin et al., 2015; Dumuid et al., 2018).

2.1.1.2 Assessment

Several methods of assessing PA have been used over the years. These methods can be broadly divided into two types: subjective (e.g., self-report, parent-report, and direct observation) and objective (e.g., pedometers, heart rate monitors, accelerometers, multi-sensor devices, indirect calorimetry, and doubly labelled water) (Ainsworth et al., 2015; Silfee et al., 2018). The doubly labelled water technique, while providing accurate assessments of energy expenditure is, however, burdensome to perform, costly and cannot be directly used to measure energy expenditure resulting from PA (Lamonte & Ainsworth, 2001). Indirect calorimetry can also be used to measure energy expenditure but it is difficult to carry out in everyday life (Armstrong & Welsman, 2006).

Due to the complexity of implementing indirect calorimetry or doubly labelled water, subjective methods of assessing PA have frequently been used, especially in large prospective cohort studies. The advantages of subjective methods are their feasibility, relative simplicity and low costs of administration, i.e., staffing, plus the fact that they are non-invasive (see e.g., Pettee Gabriel et al., 2012; Troiano et al., 2012). However, subjective methods have limitations, such as susceptibility to recall bias, poor cognition, misinterpretations of questions and reporting bias induced, for example, by social desirability (Adams et al., 2005;

Ainsworth et al., 2015; Durante & Ainsworth, 1996; Pettee Gabriel et al., 2012). Researchers using self-report data on PA need to be aware that it is not possible to accurately quantify PA using subjective methods (Pettee Gabriel et al., 2012). Summary variables based on subjective self-reports are not estimates of actual behavior but those of perceived behavior (Pettee Gabriel et al., 2012).

Due to the potential for subjective methods to yield biased results, wearable monitoring devices are being developed and increasingly used in research. A systematic review concluded that measuring PA objectively with wearable devices in research increased from 4.4% to 70.6% from 2006 to 2016 (Silfee et al., 2018). These devices can assess PA in more accessible ways than the doubly labelled technique or indirect calorimetry and, also, more objectively than the more subjective methods of PA, such as questionnaires, recall or diaries. Wearable devices measure different aspects of PA. For example, pedometers measure the number of steps taken over a period of time while accelerometers record movement through piezo-electric transducers and microprocessors that convert recorded accelerations to a quantifiable digital signal referred to as "counts" or "bouts" (Armstrong & Welsman, 2006). However, wearable devices do not measure all types of PA. For example, accelerometers are not sensitive to cycling or locomotion on an inclined surface (Armstrong & Welsman, 2006) and not all devices can be used during water-based activities. PA monitors can be rather costly when compared to self-reported data and experienced as a burden by participants. Moreover, it is not obvious what PA occurs during leisure and what during working hours (Troiano et al., 2012). Diaries, in turn, can help to distinguish work-related PA from LTPA.

While subjective and objective methods for measuring PA both have limitations, device-based data are more accurate and provide more consistent results than self-reported data (Prince et al., 2020; Skender et al., 2016). Nonetheless, to acquire a thorough understanding of PA behavior, researchers have been recommended to include both wearable devices and questionnaires in studies as the two methods assess slightly different aspects and dimensions of PA (Skender et al., 2016). Subjective methods are suitable for assessing the type or context of PA while objective methods better quantify amounts of movement or other PA signals (Troiano et al., 2012).

In this dissertation, self-reported questionnaires were used to assess LTPA and these data were validated with objectively measured data (Hirvensalo et al., 2017). Of the different LTPA questions in the YFS, those that described the frequency of LTPA and the duration of vigorous LTPA showed the strongest correlation with the pedometer data ($r = 0.28 - 0.44$, $p \leqslant 0.010$) (Hirvensalo et al., 2017). The use of subjective LTPA measures enabled LTPA to be studied over a long period of time (data collected between 1980 and 2011), i.e., from childhood to middle age, and compared across different follow-ups. Moreover, the YFS, which is a large population-based study, was initiated in 1980 when objective measures of PA were not yet used or even generally available (Troiano, 2005).

2.1.1.3 Physical activity and inactivity during the life course

Physical inactivity is a health risk factor contributing to 3,2 million deaths and 69,3 million disability-adjusted life years each year (Lim et al., 2012). Based on research findings (Physical Activity Guidelines Advisory Committee, 2008, 2018), global recommendations for PA have been developed by the World Health Organization (Bull et al., 2020). The recommendations serve as a central component of a comprehensive and coherent governance and policy framework for public health action and in establishing national PA guidelines. For example, the Finnish PA guidelines for children and adolescents (Ministry of Education and Culture, 2021) and for adults (UKK Institute, 2019) were created in accordance with the global guidelines on PA. The most recent World Health Organization´s guidelines on PA advising adults (aged 18-64 years) to do 150-300 minutes of moderate-intensity or 75-150 minutes of vigorous-intensity aerobic PA or a combination of the two throughout the week plus strength training at least twice a week (Bull et al., 2020) remain largely the same as those developed in 2010 (World Health Organization, 2010). Children and adolescents (aged 5-17 years) were encouraged to engage in at least 60 minutes of MVPA daily, including activities that strengthen the muscles and bones (Bull et al., 2020). In addition, reducing sedentary behavior is recommended across all age groups and abilities (Bull et al., 2020). Note that the volume of PA stipulated for meeting the PA recommendations is greater for children and adolescents than it is for adults.

Self-report data indicate that, globally, approximately 80% of adolescents and a quarter of adults do not meet the World Health Organization´s recommendations (Guthold et al., 2020; Sallis et al., 2016). Since the availability of nationally representative, objectively measured PA data is limited to only a few, mainly high-income, countries, PA data gathered with wearable monitors is not yet available for the estimation of global PA levels (Sallis et al., 2016). Older adults have been found to be insufficiently active to a larger extent than younger adults (Rhodes et al., 2017). Finland is no exception: in 2018, according to objectively measured PA data, 34% of 9- to 15 year-old children and adolescents met the PA recommendations (Kämppi et al., 2018) compared to 39% of adult Finnish men and 34% of adult Finnish women in 2017 (Borodulin & Wennman, 2019).

Thus, the prevalence of physical inactivity is high in almost all age groups throughout the life course, with the overall level of PA decreasing with age (Corder et al., 2019; Ekelund et al., 2011; Hallal et al., 2012; Ozemek et al., 2019; Tremblay et al., 2016). Childhood and adolescence have previously been described as the life phases when the decline in PA level begins (Jago et al., 2008; Sallis et al., 2000). A meta-analysis of data on PA decline from adolescence to early adulthood (13-30 years) concluded that MVPA declined by approximately 13% from the baseline value, and, based on the findings of studies using objective measures of PA, up to 17% (Corder et al., 2019). It has also been reported that PA declines rapidly already during childhood, with the greatest age-related differences detected in elementary school rather than during adolescence (Trost et al., 2002), and that the decline often continues throughout childhood and into adulthood (Janz et al., 2005; Kimm et al., 2000; Raudsepp et al., 2008).

Tracking refers to the tendency of individuals to maintain their rank within a group over time when compared to their peers (Malina, 2001b). Previous longitudinal studies show that many health-related behaviors, including PA, tend to track over time (Bjelland et al., 2013; Busschaert et al., 2015; Hayes et al., 2019; Lien et al., 2001; Telama, 2009; Telama et al., 2014). PA behavior tracks at a low or moderate level during individuals´ different life phases, such as childhood, adolescence or adulthood, and in transitions from one life phase to another (Hayes et al., 2019; Malina, 2001b; Telama, 2009). When compared to higher PA levels, inactivity and low activity, especially, tend to predict the same PA ranking in the future (Telama, 2009). When compared to adulthood, PA tracks at a lower level in childhood and during life phase transitions, for example, from childhood to adolescence or from adolescence to adulthood (Telama, 2009). Thus, since PA tracks at best at a moderate level, those whose PA ranking changes, even increases, over time have remained unresearched.

2.1.1.4 Factors related to physical activity

Studies examining the factors related to or explaining individuals' PA level have increased substantially in the 21st century and especially during recent decades (Sallis et al., 2016). These studies have sought to determine the reasons explaining PA behavior in order to be able to promote health through PA more effectively in different groups and during different life phases.

The relationship between different aspects of socioeconomic status (SES) and PA has been highly studied. A review study on the socio-economic determinants of PA across the life course concluded that LTPA and SES were positively associated and occupational PA and SES were negatively associated among adults (O'Donoghue et al., 2018). No consistent associations between PA and SES among children and adolescents were observed (O'Donoghue et al., 2018). In Finland, however, higher parental SES has been found to associate positively with the PA level of their children (Ministry of Social Affairs and Health, 2013). Overall, in high-income countries higher SES has been found to correlate with a higher PA level (Bauman et al., 2012), whereas the findings for low- and middle-income countries suggest that higher SES correlates inversely with PA (Sallis et al., 2016). Another finding specifically concerning low- and middle-income countries was that urban (vs. rural) living was negatively associated with PA level (Sallis et al., 2016).

Among children and adolescents, higher PA has consistently been found to correlate positively with previous PA, male sex, younger age, higher self-efficacy, participating in extra-curricular sport, higher social support from family or peers, and access to destinations and open space such as green areas or trails (Bauman et al., 2012; Rhodes et al., 2017; Sallis et al., 2016). Individual and environmental factors correlating positively with PA among Finnish children and adolescents have been reported to be peer support for PA, promoting self-directed PA, and lowering the barriers (e.g., via the design and promotion of neighborhood PA facilities) (Mehtälä et al., 2020). Ethnicity has been found to be associated with

PA, with Caucasian children and adolescents in Europe and North America having higher probability of being physically active when compared to minorities or migrant peers (Rhodes et al., 2017). Similar results have been reported in the Finnish population: the PA level of migrants, especially migrant women, was lower than that of the indigenous Finnish population in all age groups (Ministry of Social Affairs and Health, 2013).

Among adults and elderly, consistent positive correlates with PA have found to include good health status, known benefits of being active, previous higher PA, younger age, higher education, male sex, higher self-efficacy, higher social support from peers, access to open spaces and destinations and enjoyable scenery (Bauman et al., 2012; Choi et al., 2017; Rhodes et al., 2017; Sallis et al., 2016). In Finland, there is a gender-related exception: the prevalence of LTPA among adults increased between 1972 and 2002, especially in women, such that gender differences in LTPA were no longer detected in 2002 (Borodulin et al., 2008). LTPA increased from 66% to 77% in men and from 49% to 76% in women (Borodulin et al., 2008). However, differences in LTPA have grown wider across educational and body mass index (BMI) groups, with less educated and more overweight individuals participating in less LTPA (Borodulin, Harald, et al., 2016). Globally, obesity and overweight have been reported to associate negatively with PA in adults (Sallis et al., 2016).

Life events have been suggested to explain the changes occurring in PA behavior during the life course. For example, transitions from one educational level to the next, getting married, having children, change in employment, change in residence, and retirement have all been suggested to impact PA (Allender et al., 2008; Corder et al., 2009; Hirvensalo & Lintunen, 2011). It remains unclear which life events or life transitions are the most important in different populations and what specific factors are associated with the changes that occur in PA during specific life phases (Corder et al., 2009).

2.1.2 Dietary behavior

Dietary behavior is a complex behavior that has been described in the literature by a diversity of terms, such as diet, nutrition, dietary intake, eating behavior, eating habits and food choice. Due to the inconsistent use of these terms, an interdisciplinary taxonomy of dietary behavior has been proposed (Stok et al., 2018). The taxonomy consists of 34 different terms categorized under three main headings: 1) Food choice (i.e., behaviors or other factors occurring before food reaches the mouth, such as color and aroma of the food, individual’s biological and social factors, culture, income and policy (Chen & Antonelli, 2020)), 2) Eating behavior (i.e., outcomes concerning the actual act of consumption) and 3) Dietary intake / Nutrition (i.e., outcomes breaking down the content of what was consumed)(Stok et al., 2018).

The present dissertation focused on studying eating habits and portion sizes (Amougou et al., 2016), both of which come under the Eating behavior category of the taxonomy (Stok et al., 2018). Eating habits are defined as habitual eating behaviors that an individual has developed over time (Gardner, 2015). Under the

Dietary intake category, the healthiness of eating habits was studied. Healthiness refers to the extent to which the foods or beverages consumed are considered to have a negative (e.g., sugar-sweetened beverages are considered unhealthy) or positive (e.g., vegetables, legumes and fruits are considered healthy) effect on the individual's health (Ocké, 2013). Since multiple aspects of dietary behavior from two different categories were studied in this dissertation, the term dietary behavior is used as an umbrella term. As recommended in the literature (Jacobs & Tapsell, 2007), whole foods instead of nutrients (e.g., specific vitamins) were used as units of dietary intake in this study.

In 2015, dietary risks accounted for 12% of total disability-adjusted life years in men and for 9% in women worldwide (Forouzanfar et al., 2016). Diets high in sodium and low in fruit were associated with cardiovascular and circulatory diseases, cancers, diabetes and urogenital, blood, and endocrine diseases (Forouzanfar et al., 2016). The Nordic nutrition recommendations were updated in 2012 (Nordic Council of Ministers, 2012) and Finnish food recommendations follow them (Fogelholm et al., 2014). The recommendations included increasing the intake of vegetables, legumes, fruits, berries, nuts, seeds, fish and seafood and limiting that of processed and red meat, beverages and foods with added sugar, salt, and alcohol (Nordic Council of Ministers, 2012). In addition, wholegrain cereals instead of refined cereals, vegetable oils instead of butter, and low-fat instead of high-fat dairy products were recommended (Nordic Council of Ministers, 2012). Adults were recommended to consume 500 grams of fruits and vegetables daily (Fogelholm et al., 2014). Only 22% of women and 14% of men in Finland meet this recommendation (Valsta et al., 2018) and worldwide the number is low (Miller et al., 2016).

2.1.3 Sedentary behavior

Sedentary behavior is defined as any waking behavior characterized by an energy expenditure of 1.5 METs or lower while in a sitting, lying, or reclining posture (Bull et al., 2020; Sedentary Behaviour Research Network, 2012; Tremblay et al., 2017). Sedentary behavior should be distinguished from physical inactivity (Pettee Gabriel et al., 2012; Tremblay et al., 2017) which is usually defined as not meeting the present PA recommendations (Bull et al., 2020; Tremblay et al., 2017). A person might accumulate hours of sedentary time during the day, but still be physically active according to PA recommendations (for example, having an hour of MVPA daily) whereas another person might have only a few sedentary hours in a day but a low PA intensity level (Owen et al., 2010). The worst scenario health-wise is having a high amount of sedentary time and being physically inactive, as there is strong evidence to show that the hazardous effects of sedentary behavior are more pronounced in physically inactive people (Katzmarzyk et al., 2019).

Research on sedentary behavior has increased since the beginning of the 21st century (Katzmarzyk et al., 2019; Owen et al., 2010). The updated report on sedentary behavior and health by the 2018 Physical Activity Guidelines Advisory

Committee found convincing evidence that high sedentary time, such as prolonged television viewing (TV) (Sun et al., 2015) and high total screen time (Grøntved et al., 2014), increase the risk for all-cause and cardiovascular disease mortality and incident cardiovascular disease and type 2 diabetes (Katzmarzyk et al., 2019). Sedentary behavior was also associated with incident endometrial, colon and lung cancer, although the evidence for this was not as strong (Katzmarzyk et al., 2019). Worldwide, adults spend an average of 6 to 8 hours per day sedentary according to data collected with accelerometers (Young et al., 2016). In Finland, adults exhibit the same trend, with men being sedentary for nearly 8 hours and women slightly over seven hours on a weekday (Finnish Institute for Health and Welfare (THL), 2017). Moreover, 7- to 14-year-old Finnish children were found to be sedentary for over 7 hours of their waking time (Husu et al., 2016).

Sedentary behavior may be assessed based on overall sedentary time or by selected types of sedentary behavior. It can be nondiscretionary (i.e., sitting while driving or during work or school hours) or discretionary (sitting while viewing television, reading, playing video games, or using computers or other electronic devices during leisure) (Pettee Gabriel et al., 2012). Of the different sedentary behavior domains, TV time has been found to be the one most associated with adverse health and behavioral outcomes (Basterra-Gortari et al., 2014; Helajärvi et al., 2014; Kim et al., 2013). Screen time and TV time during leisure were used as measures of sedentary behavior in this dissertation. Recreational screen time (i.e., screen time during leisure) is defined as the time spent on screen-based behaviors that are not related to work or school (Tremblay et al., 2017).

In 2017, 26% of Finnish adult men and 19% of adult women of working age reported at least three hours of recreational screen time daily with total mean values of 3.1 hours per day among men and 2.8 among women (Koponen et al., 2018). The use of electronic devices for watching programs, other than traditional television broadcasts (i.e., streaming services, watching previous recordings, or using dvd / blue-ray), has increased in Finland in the last decade. In 2016, Finns used electronic devices for watching programs 24 minutes per day whereas the number had increased to 50 minutes per day by the year 2021 (Finnpanel, 2021). Nonetheless, traditional television broadcasts still remain the most prevalent source of program watching in Finland with Finns watching television approximately 2 hours and 45 minutes on a daily basis (Finnpanel, 2021).

2.1.4 Sleeping behavior

Sleep is defined as spontaneous and reversible resting that can be characterized by the relative inactivity of the voluntary muscles and nervous system (Carskadon & Dement, 2011). Consciousness, responsiveness to stimuli, and interactions with the environment are reduced during sleeping (Carskadon & Dement, 2011). Energy expenditure during sleeping amounts to less than one MET (Ainsworth et al., 2011).

Sleep difficulties have been found to increase the risk for dementia (Shi et al., 2018) and insomnia has been reported to associate with an increased risk of developing or dying from cardiovascular disease (Sofi et al., 2014). Prolonged and shortened sleep duration, especially when sleeping consistently for five hours or less per night (Cappuccio et al., 2011), have also been associated with higher risk for non-communicable diseases and mortality (Gallicchio & Kalesan, 2009; Jike et al., 2018; Liu et al., 2017). Based on these findings, the recommended sleep duration for adults is 7 to 9 hours per night (Hirshkowitz et al., 2015).

A small but significant decreasing trend in sleep duration has been observed during recent decades in the Finnish general population, especially among employed middle-aged men (Kronholm et al., 2008). The proportion of people sleeping 7 hours per night increased and the proportion of 8-hour sleepers decreased between the years 1972 and 2005 (Kronholm et al., 2008). A systematic review of secular trends in sleep duration across 15 countries from the 1960s up to the 2000s found sleep duration to have increased in seven countries and decreased in six, Finland being among the decreasers (Bin et al., 2012). Luckily, from the public health perspective, the proportions of extremely short sleepers (<6h/night) or long sleepers (>9h/night) has remained unchanged in Finland (Kronholm et al., 2008). In this dissertation, meeting the recommended 7-9 hours of sleep per night was studied in relation to PA development.

Meanwhile, the proportion of Finnish adults suffering from occasional insomnia-related symptoms has increased from less than 30% in the 1970s to nearly 45% in the 21st century (Kronholm et al., 2016). Insomnia has been defined in multiple ways. For example, the focus has been solely on the nocturnal symptoms occurring or has also included features of daytime impairment or sleep dissatisfaction (Lineberger et al., 2006). In the present study, sleep difficulties in adults were studied by using Jenkins Sleep Scale (Jenkins et al., 1988). The scale divides sleep difficulties into four categories: difficulties falling asleep, nocturnal awakenings, difficulties staying asleep (including too-early awakenings), and non-restorative sleep (Jenkins et al., 1988).

2.1.5 Smoking

Traditionally, smoking has been defined as an occasional or regular addictive habit of inhaling the smoke of burning tobacco whether from cigarettes, pipes or cigars (Leone et al., 2010). This was the definition adopted in this study (using snuff or e-cigarettes were not studied). However, it has also been suggested that smoking should be defined as a chemical toxicosis which may have detrimental effects of either an acute or chronic type on different structures of the body, such as the cardiovascular system, respiratory system or epithelial glands (Leone et al., 2010). Thus, the definition itself should include the risks of smoking.

Globally, smoking is the second leading risk factor for early death and disability (Forouzanfar et al., 2016), killing more than 8 million people each year (World Health Organization, 2019). In 2015, the age-standardized prevalence of daily smoking was 25% among men and 5% among women worldwide (Reitsma et al., 2017). In Finland, the corresponding proportions were 19% and 16%, respectively (Reitsma et al., 2017). While a relative reduction in global smoking rates was observed between the years 1990-2015 (28% reduction in men and 34% in women) (Reitsma et al., 2017), over one billion adults and 24 million adolescents aged 13-15 years continue to smoke worldwide (World Health Organization, 2019).

2.1.6 Binge drinking

Alcohol use is related to many chronic and acute disease outcomes (Rehm et al., 2010). In 2015, alcohol use (including drug use) was ranked as the fifth-leading risk factor globally for the burden of disease in men (6.6%) and eleventh in women (2%) (Forouzanfar et al., 2016). From the 1960s until 2008, alcohol consumption per capita tripled in Finland (Mäkelä et al., 2012), and even larger increases were found for indicators of alcohol-induced harm, such as the rate of assaults and alcohol-related mortality including alcohol poisoning, alcohol-induced cirrhosis of the liver, alcoholism, and alcohol psychoses (Mäkelä, 2011). However, a decreasing trend in alcohol consumption has been observed ever since, with recent statistics showing a decrease of as much as 5,2% in total alcohol consumption between 2019 and 2020 (Jääskeläinen & Virtanen, 2021).

While the volume of alcohol consumed is associated with increased risk for many diseases, so is the pattern of consumption (World Health Organization, 2018). Light to moderate alcohol consumption has been found to have a protective role against certain diseases, if alcohol consumption habits do not include episodes of binge drinking (Rehm et al., 2010). Binge drinking seems to have hazardous effects on cardiovascular disease morbidity and mortality in contrast to reasonable alcohol consumption, which has even been suggested to have health protective effects (Murray et al., 2002). Hence, binge drinking is one of the most important measures used in epidemiological studies to determine the burden of disease caused by the use of alcohol (World Health Organization, 2018).

Binge drinking is synonym for heavy episodic drinking, risky single occasion drinking, heavy sessional drinking, heavy drinking and risk drinking (Kuntsche et al., 2017). Binge drinking is commonly defined as the consumption of a given amount of alcohol (often five or more units for men and four or more for women) on a single, relatively short, occasion (Kuntsche et al., 2017; Wechsler & Isaac, 1992). In the present study, the cut-off value for binge drinking was six or more alcoholic drinks on one occasion and is the definition frequently used in Nordic studies (see e.g., Mäkelä et al., 2001 & Koponen et al., 2018). Worldwide, the prevalence of binge drinking (defined as 60 or more grams of pure alcohol on at least one occasion at least once per month) in the adult population in 2016 was 18% (World Health Organization, 2018). In Finland, over 30% of adult men and about 10% of women reported binge drinking at least once a month in 2017 (Koponen et al., 2018). In Finland, binge drinking is more prevalent among manual workers and light drinking more prevalent among people with higher SES (Härkönen, 2013, pp. 43-46).

2.2 The role of physical activity in a healthy lifestyle

Combinations of multiple unhealthy behaviors have found to be more detrimental to health than the same behaviors individually (Berrigan et al., 2003; Ding et al., 2015; Poortinga, 2007b). A study examining PA, smoking, alcohol intake, diet, television viewing, and sleep concluded that a combination of multiple health-compromising behaviors was strongly associated with cardiovascular disease and all-cause mortality (Foster et al., 2018). Another study showed that individuals who followed four or more healthy behaviors (physically active lifestyle, non-smoking, no excessive alcohol use, a healthy diet, and had normal weight) had a 66% lower overall mortality risk than those who reported several unhealthy behaviors (Loef & Walach, 2012). Thus, promoting the adoption of multiple healthy behaviors seems to be essential for improving public health.

A systematic review of data gathered from clustering studies concluded that unhealthy behaviors (smoking, unhealthy diet, excessive alcohol use and physical inactivity) tend to accumulate in same individuals and that healthy behaviors also accumulate in the same individuals (Noble et al., 2015). In particular, excessive alcohol use was found to cluster with smoking (Noble et al., 2015). The opposite results have also been reported: based on a large analysis conducted in North America, alcohol use, smoking, exercise, and diet together accounted for only 1% of the shared variance, indicating that these four health-related behaviors are largely unrelated to one another (Newsom et al., 2005). Thus, more research is needed to better understand whether overall negative and overall positive health patterns exist.

It has been suggested that change in one behavior may lead to change in another behavior, especially if both behaviors are either health-enhancing or health-compromising (Lippke et al., 2012). This is known as the gateway effect (Dutton et al., 2008; Tucker & Reicks, 2002). It has been proposed that PA in particular might play an important role in the adoption of multiple healthy lifestyle choices, e.g., eating healthier (Fleig et al., 2015; Pronk et al., 2004). However, the findings on whether PA could serve as a gateway behavior for a healthy lifestyle remain conflicting.

Two intervention studies found that improvements in PA did not lead to the adoption of a healthier diet (Dutton et al., 2008; Wilcox et al., 2000) while a few cross-sectional studies have suggested that PA is associated with healthier eating (Blakely et al., 2004; Tucker & Reicks, 2002). A longitudinal study showed that adults who increased their PA level also improved their diet when compared to their decreasingly active peers (Parsons et al., 2006). Being physically active in adulthood was also associated with a higher consumption of fruits and vegetables (Grosso et al., 2017).

With respect to PA and sleeping, in 2008, the Physical Activity Guidelines Advisory Committee concluded in its report that only a few observational, population-based studies had found regular PA to be associated with lower odds for disrupted and insufficient sleep (Physical Activity Guidelines Advisory

Committee, 2008). However, with the increasing research interest in the area, the updated umbrella review in 2021 reported stronger evidence for positive associations between PA and favorable sleep outcomes (Kline et al., 2021).

Regularly physically active people have often been found to smoke less than physically inactive people (Badicu et al., 2020; Kaczynski et al., 2008; Nigg et al., 2009). Physical inactivity in adolescence has been reported to predict both smoking (Kujala et al., 2007) and weekly alcohol intoxication (Korhonen et al., 2009) in young adulthood. At the same time, cross-sectional studies have reported positive association between alcohol consumption and PA (Musselman & Rutledge, 2010; Poortinga, 2007a). Thus, the relationship between physical inactivity and higher alcohol use is ambiguous. More research, especially with a prospective design and long follow-up time, is needed to better understand which health-related behaviors are associated with PA during the life course and the role of PA in adopting a healthy lifestyle.

2.3 Trajectory modeling for studying behavioral development

Recent advances in statistical methods have enabled the identification of multiple homogeneous subgroups in a heterogeneous population in a longitudinal data (Muthén & Muthén, 2017; Nagin, 2005). This method, called trajectory modeling, has become a rather popular approach in studying diversity in developmental pathways of PA over time. Longitudinal studies using trajectory modeling have provided novel insights into inter- and intra-individual differences in PA (Reilly, 2016).

A developmental trajectory can be defined as a growth curve describing the course of individual's behavior over age or time (Nagin, 1999). Traditionally change over time has been studied using two measurement points (baseline and one follow-up), while studies using trajectory modeling have used multiple (at least three) measurement points, enabling the study of linear as well as curvilinear change over time (Muthén & Muthén, 2000). Thus, variation in the magnitude, rate and timing of possible change can be studied. The ability to detect change as well as stability over time can be seen as a strength of trajectory modeling (Nagin & Tremblay, 2005). Another advantage of trajectory modeling is that rather than assuming the existence of distinct trajectories in a population or setting threshold values before modeling, the trajectories are inferred from the data (Muthén & Muthén, 2000; Nagin, 2005; Warren et al., 2017).

Several statistical methods have been used to identify diverse trajectories, such as latent class analyses, latent profile analyses, latent class growth analyses, growth mixture modeling and group-based trajectory modeling. These statistical approaches can be placed under the umbrella term finite mixture modeling (Jung & Wickrama, 2008). Finite mixture models are person-centered approaches aiming at probabilistically assigning individuals into distinct subgroups (i.e., trajectories or latent classes) so that individuals in a subgroup share more similarities than individuals between subgroups (Berlin et al., 2014; Jung & Wickrama, 2008).

In addition, the possibility to integrate variable- and person-centered approaches to, for example, latent class analysis, latent class growth analysis, growth mixture modeling, and general growth mixture modeling has also been proposed as a strength of these models (Muthén & Muthén, 2000). Latent variables, in turn, are unobservable quantities (e.g., intelligence, behavior) that can only be incompletely measured by tests or questionnaires (Schafer & Graham, 2002).

Researchers using trajectory modeling should also be aware of its drawbacks (Nagin & Tremblay, 2005; Twisk, 2014; Twisk & Hoekstra, 2012; Warren et al., 2017). For example, trajectory class membership is not certain as it only describes the probability of a participant's membership of a trajectory, and the number of trajectory classes is not fixed (Jung & Wickrama, 2008; Warren et al., 2017). With these caveats in mind, the present study used trajectory modeling to identify the key PA subgroups and critical windows of life at which to target PA promotion and interventions that could contribute to the enhancement of public health.

3 AIMS OF THE STUDY

3.1 Research questions and hypotheses

This doctoral dissertation forms part of a larger research project under the title "The Role of Physical Activity in Healthy Behavior". The purpose of this project, and hence also the purpose of the present study, was to identify developmental pathways (i.e., trajectories) of LTPA during the life course between and within women and men in the general population and to investigate the role of inter- and intra-individual LTPA development in the adoption of a healthy lifestyle. More specifically, the interest was in the associations of different LTPA trajectories with other health-related behaviors, including dietary behavior, sleeping, binge drinking, smoking, and screen time / TV time during leisure. The specific research questions addressed in Studies I-IV were:

1. How does PA develop during the life course from childhood to old age between and within individuals in the general population and what factors related to PA development in previous PA trajectory studies (I)?

2. How are different LTPA trajectories associated with TV time trajectories in adult women and men (II)?

3. How are different LTPA trajectories associated with fruit and vegetable consumption (FVC) from childhood to middle age in women and men (III)?

4. Do health-related behaviors in middle age, including diet, screen time during leisure, smoking, binge drinking, sleep difficulties, and sleep duration, differ in women and men according to their LTPA trajectory membership from childhood to middle age (IV)?

It was hypothesized that persistent LTPA during childhood and adolescence would be associated with the other health-protective behaviors studied, especially dietary behavior, and, vice versa, persistent inactivity / low-activity would be associated with health-compromising behaviors. In addition, an increasing or decreasing LTPA level was expected to have the potential to develop in tandem with changes in dietary behavior or TV time, irrespective of confounding factors such as BMI or educational level.

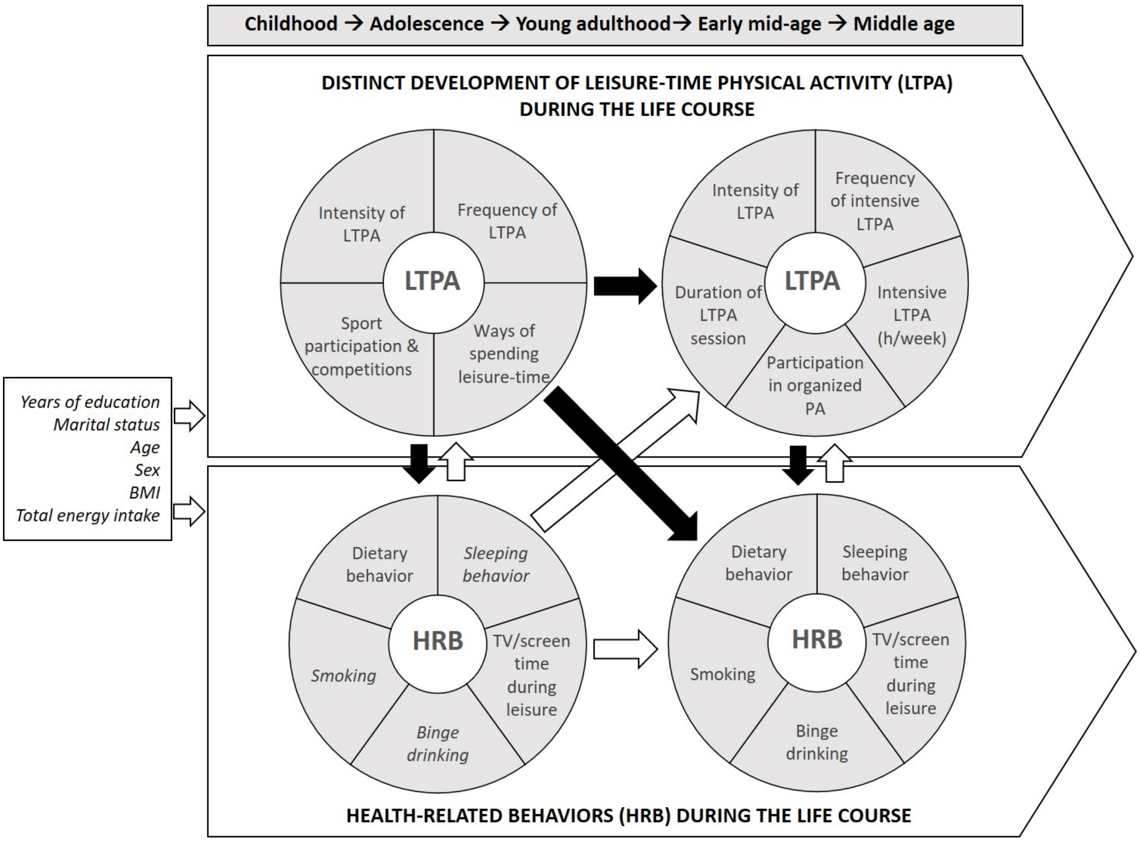
3.2 Conceptual framework of the study

In 2001, Malina introduced a modified version of the framework originally designed by Blair et al. (1989) in "Exercise and fitness in childhood: implications for a lifetime health" (Malina, 2001a). Malina's modified framework described the different links between PA in childhood and adolescence with PA and health in childhood, adolescence, and adulthood (Malina, 2001a). Although the framework was not originally designed to illustrate the associations between LTPA and other health-related behaviors, it provided the foundation for the conceptual framework of Studies II, III and IV of this dissertation.

The further modified framework aimed to demonstrate the potential links between the diverse development of LTPA from childhood to middle age and other health-related behaviors (Figure 2). Thus, the framework describes how persistent or increasing LTPA throughout the life course may potentially help people to adopt other health-protective behaviors whereas, conversely, decreasing LTPA, inactivity or low activity may be related to health-compromising behaviors. As observational studies can include reverse causation, the arrows between LTPA and health-related behaviors are bidirectional where relevant in Figure 2. The black arrows indicate the associations under study. The variables used in the present study are marked within the segments of the circles in Figure 2.

Definition of age ranges concerning life phases, such as childhood, adolescence and adulthood, differ between studies to some extent (see e.g., Bull et al., 2020; Rovio et al., 2018; World Health Organization, 2001, 2021). Defining the age range for the life phases was a challenge for the current dissertation as well, as studies included in the systematic review (I) defined life phases slightly differently. In the current dissertation, the following ages are applied for different life phases when possible: a) childhood (participants under 13 years of age); b) adolescence (participants aged 13-17 years); c) adulthood (participants aged 18-64 years); and d) older adulthood (participants aged 65 or older). Young adults were defined as 18-24 years (World Health Organization, 2021). While the definition of middle age is often from 40 to 60 years of age (Encyclopaedia Britannica, 2007), the definition seems to be in constant change due to improved life expectancy (Rotkirch, 2021) and varies widely from, for example, 25-49 (Reker, 2005) to 45-65 years (Livingston et al., 2020) of age. It has even been suggested to name people aged 65-75 years as late middle-aged instead of older adults (Rotkirch, 2021).

In the Figure 2, early mid-age refers approximately to people around 30 years of age and middle age to people around 40 to 50 years of age (II-IV).



The black arrows indicate the associations under study. Variables used as covariates are shown in *italics*. *LTPA* Leisure-time physical activity; *PA* Physical activity; *HRB* Health-related behaviors; *TV* television viewing; *BMI* Body mass index.

FIGURE 2 Conceptual framework of Studies II-IV.

4 METHODS

4.1 Systematic review (I)

The first study systematically reviewed the literature using finite mixture modeling (also referred to as trajectory modeling in this dissertation) to identify longitudinal PA trajectories and related factors (e.g., determinants, predictors, and outcomes) during different life phases in the general population. The review followed a pre-defined methodological approach (Figure 3). The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist (Moher et al., 2015) was applied and the review protocol was registered with the International Prospective Register of Systematic Reviews (PROSPERO) (Registration number: CRD42018088120).

Systematic searches were made in the PubMed (Medline), Web of Science, and CINAHL databases. The search terms were defined according to the research questions and synonyms for the different terms were used to broaden the search. Articles had to contain the term trajectory and, for each of the following fields (a-c), at least one of the italicized terms: (a) for PA: *physical activity, physical inactivity, sport, exercise,* or *team participation*; (b) for the study design: *longitudinal, cohort, prospective, panel,* or *follow-up*; and (c) for distinct trajectory classes: *group, cluster, class, profile, subgroup,* or *classification*. To be included in the systematic review, studies had to meet the following criteria: be longitudinal in design; report data on children, adolescents, adults or older adults in the general population; identify more than one trajectory class with three or more measurement points for either PA, exercise or sport participation; use finite mixture modeling for the identification of trajectories; be published between the year 2000 and 13th of February 2018; and be published in English. To establish inter-rater reliability, studies were selected by two authors independently (Lounassalo and Salin). In cases of disagreement, other authors were consulted (Hirvensalo, Kankaanpää or Tolvanen). The search strategy and exclusion criteria are reported in greater detail in the original paper (I).

The following data were extracted from the included articles: study aims, description of the study, study sample, statistical approach, data collection and PA variables, description of the trajectory classes identified, factors related to the PA trajectories, and main findings in relation to trajectory class membership. The first author performed the data extraction, consulting the other authors when necessary. After the data extraction, the articles were grouped according to the participants' age. The PA trajectories reported in the studies were subsumed under the PA trajectory category that best described the name and shape of the trajectory.

The methodological quality of each included study was assessed by two independent authors, who consulted the other authors when necessary. Modified versions of the Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies (National Heart Lung and Blood Institute, 2018) and Guidelines for Reporting on Latent Trajectory Studies checklist (Van de Schoot et al., 2017) were used for assessing the quality of the included studies. The questions chosen for the quality assessment were designed to assess, for example, attrition bias, performance bias, detection bias, and selection bias concerning the final number of trajectory classes chosen. Each included study was evaluated and its quality categorized as poor (scored from 0 to 5), fair (6 to 11), or good (12 to 16).

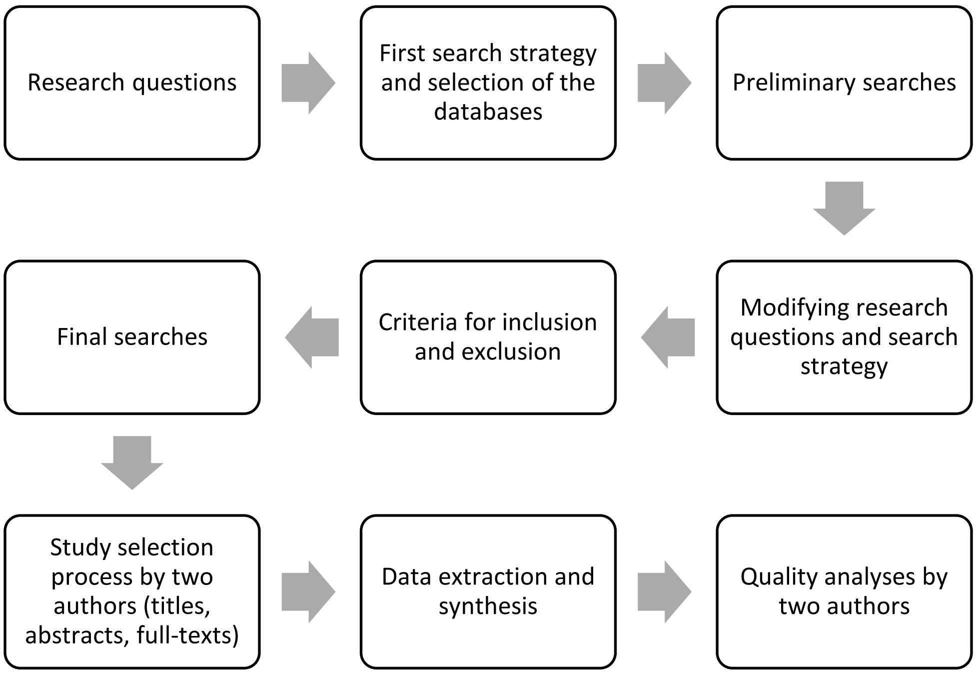


FIGURE 3 The systematic review process.

4.2 Cardiovascular Risk in Young Finns Study (YFS) (II-IV)

4.2.1 Study design, data, and participants

The data for Studies II-IV were drawn from the YFS, an ongoing population-based multicenter follow-up study involving five Finnish university cities (Helsinki, Kuopio, Oulu, Tampere, and Turku) and their rural surroundings. The YFS was originally designed to identify potential coronary heart disease risk factors and their determinants in Finnish children and adolescents (Åkerblom et al., 1985; Raitakari et al., 2008). A comprehensive number of variables related to cardiovascular risk factors have been measured in the YFS by using, for example, questionnaires, physical measurements, ultrasound scans, and blood tests. The present study used the self-reported data on health-related behaviors.

The original YFS sample was randomly selected from the national population register and comprised 1764 Finnish boys and 1832 girls (83% of those invited) from different socioeconomic backgrounds and living arrangements. At the YFS baseline in 1980, six age cohorts, born in 1962, 1965, 1968, 1971, 1974, and 1977, were included in the study (Table 1) (Åkerblom et al., 1985, 1991; Raitakari et al., 2008). Follow-up studies were conducted in 1983, 1986, 1989, 1992, 2001, 2007 and 2011-12. The participants were 3-18 years at baseline and 33-49 years at the 2011-12 follow-up, when 2060 subjects (55% female) were assessed. Participation rates in the follow-up studies have varied between 60-80%. Previous attrition analyses showed that while participants were older and more often female than those lost to follow-up, the differences between the two groups in coronary risk factors, LTPA, BMI, or parental years of education were small. Some of those who dropped out from the YFS at an early stage returned to participate in later follow-ups. A more detailed description of the YFS protocol has been published previously (Raitakari et al., 2008).

TABLE 1 Study design and number of participants in the Cardiovascular Risk in Young Finns Study.

Measurement year	n total	Age of participants in the six age cohorts															
1980	3596	3	6	9	12	15	18										
1983	2991		6	9	12	15	18	21									
1986	2779			9	12	15	18	21	24								
1989	2737				12	15	18	21	24	27							
1992	2370					15	18	21	24	27	30						
2001	2620								24	27	30	33	36	39			
2007	2204										30	33	36	39	42	45	
2011–12	2060											33-34	36-37	39-40	42-43	45-46	48-49

Sample size (n) varied across Studies II-IV (Table 2). The sample in Study II comprised a total of 2934 adult participants (54% females) each with at least one measurement of self-reported LTPA or TV time. Studies III and IV examined participants from childhood to middle age. In Study III, the sample comprised 3536 participants (51% females) each with at least one measurement of LTPA and FVC. Study IV had the largest sample (n=3553; 51% females), which included participants with at least one measurement of LTPA. At baseline in 1980, boys were physically more active than girls; however, no differences in the LTPA index (to be presented later) were found at the last measurement in 2011 between men and women (see Table 1 in IV). More detailed descriptive information on the study sample can be found in the original publications (II-IV). In the YFS, the data on children under 9 years of age were reported by parents or guardians. Thereafter the data were self-reported. To avoid biased results, parent-reported data were excluded, and thus the present study was confined to participants aged 9 or older.

TABLE 2 Sample sizes, participants´ age, sex distribution and completed leisure-time physical activity measurements in Studies II-IV.

Study	n	Partici-pants´ age in years	Wo-men (%)	Number of LTPA meas-urements	Proportion of participants (%) completing the LTPA measurement times (1–8)							
					1	2	3	4	5	6	7	8
II	2934	24-49	54	3	23	26	49					
III	3536	9-49	51	8	4	7	11	13	16	19	16	14
IV	3553	9-49	51	8	6	10	15	18	23	16	8	4

LTPA Leisure-time physical activity.

4.2.2 Ethics

All four studies were conducted following the principles of good scientific practice laid down by the Helsinki Declaration. The study protocol was reviewed and approved by the Ethics Committee of the Hospital District of Southwest Finland in collaboration with the ethics committees of every university involved in the YFS. All participants or their parents / guardian in the case of children under 16 years of age gave their written informed consent prior to entering the study (Raitakari et al., 2008). Participation was voluntary and participants had the right to withdraw from the study at any point. All personal data were pseudonymized and all digital data stored and treated confidentially on the servers of the collaborating universities and protected by passwords. The funders were not involved in the design of the study, data collection, analysis, data interpretation or writing of the paper.

4.2.3 Measurements

4.2.3.1 Leisure-time physical activity

In the YFS, self-administered questionnaires have been used at each measurement point (1980-2011) to assess LTPA whereas active commuting (i.e., transport), occupational PA and household PA have only been assessed a few times. Since one main objectives of the present study was to explore the development of PA all the way from childhood to middle age, i.e., from 9 to 49 years of age, self-reported LTPA data were considered the most suitable data for the purpose.

During the years 1980-1989, the LTPA questionnaire comprised the following items: frequency and intensity of LTPA, participation in sports club training and sport competitions, and habitual ways of spending leisure-time. The LTPA questionnaire was modified after 1989 to better correspond to the LTPA behavior of the participants, who were now reaching adulthood. In the years 1992-2011, the LTPA questionnaire comprised items on the frequency and intensity of LTPA, hours spent engaged in intensive LTPA, usual duration of a LTPA session, and participation in organized PA. Responses to each item were recoded into three categories: (1) irregular activity, low activity, or inactivity; (2) regular weekly activity or moderate activity; and (3) regular daily activity or vigorous activity. The scores were then summed to create a LTPA index, with higher scores indicating higher LTPA (Table 3) (Telama et al., 2005, 2006). A more detailed description of the LTPA index can be found elsewhere (see Table S1 and S2 in (Rovio et al., 2018)).

The index has been validated previously against data collected with accelerometers and pedometers (Hirvensalo et al., 2017; Mansikkaniemi et al., 2012; Pälve, 2017, pp. 30-35), and indicators of exercise capacity (hypothetical maximal workload sustainable for 6 minutes) in a subsample of the participants (Telama et al., 2005). These validation analyses showed the LTPA questionnaire to be an acceptably valid subjective measure of LTPA.

TABLE 3 Summary of the variables used in Studies II–IV.

Variable (measurement period)	Range / unit	Study
LTPA index (1980-89):	5-14 points	III, IV
Frequency of LTPA	1-3	
Intensity of LTPA	1-3	
Participation in sports club training	1-3	
Participation in sport competitions	1-2	
Habitual ways of spending leisure-time	1-3	
LTPA index (1992-2011):	5-15 points	II, III, IV
Intensity of LTPA	1-3	
Frequency of intensive LTPA	1-3	
Hours spent / week in intensive LTPA	1-3	
Average duration of a LTPA session	1-3	
Participation in organized PA	1-3	

Variable (measurement period)	Range / unit	Study
FVC index (1980-2001)	2-12 points	III
Frequency of fruit consumption during past month	1-6	
Frequency of vegetables consumption during past month	1-6	
FVC in grams (2007-2011)	g / day	III
Intake of fruits converted to grams	g / day	
Intake of vegetables converted to grams	g / day	
Diet index (2011)	0-27	IV
Whole grain products	0-3	
Fruits	0-3	
Vegetables and legumes	0-3	
Fish	0-3	
Vegetable fats and oils	0-3	
Red meat and meat products	3-0	
Sugared beverages	3-0	
Fried and deep-fried potatoes	3-0	
Desserts	3-0	
TV time during leisure (2001-2011)	hours / day	II
Average TV time during leisure	hours / day	
Screen time during leisure (2011)	hours / day	IV
Average television and video viewing time during leisure	hours / day	
Average computer use time during leisure	hours / day	
Sleep difficulties according to Jenkins Sleep Scale (2011)	1-3*	IV
Problems in falling asleep	1-3	
Awakenings during sleep	1-3	
Difficulties staying asleep	1-3	
Tiredness after a normal night's sleep	1-3	
Usual sleep duration / night (2011)	hours / night	IV
Covariates:		
Age	years	II, IV
Sex	woman / man	II, IV
Body mass index	kg/m^2	II, III, IV
Education	years	II, III, IV
Mother's education	years	III
Marital status: in a relationship or not	yes / no	IV
Total energy intake	kcal/day	III, IV
Diet index (1989)	range 9-54	IV
Screen time during leisure (2001)	hours /day	IV
Smoking status (1989 in IV / 2001 in II)	range 1-4 / 1-2	IV, II
Binge drinking occasions (1989)	range 1-5	IV
Sleep duration (1986)	hours / night	IV
Feeling fatigue (1986)	range 1-4	IV

*1=no sleep difficulty; 2=moderate sleep difficulty; 3=severe sleep difficulty. If participants reported more than one symptom, their most frequent symptom was recorded as their degree of sleep difficulty. *LTPA* Leisure-time physical activity; *FVC* Fruit and vegetable consumption; *TV* Television viewing.

4.2.3.2 Dietary behavior

In Study III, two different self-administered questionnaires were used to collect data on participants' FVC. The FVC data collected in 1980, 1983, 1986, 1989 and 2001 with the first questionnaire was used for participants aged 9 to 27 years. Frequencies of fruit (including fruit juice) and vegetable consumption during the past month were asked separately on a scale from one (not at all or hardly ever) to six (every day). The values for the two items were summed to create an FVC index ranging from 2 to 12 (Table 3). The higher the index score, the higher the participant's FVC.

In 2007, a more comprehensive 131-item semi-quantitative food frequency questionnaire (FFQ) replaced the earlier questionnaire. The FFQ was developed and validated by comparing it to a 3-day food record issued by the Finnish National Institute for Health and Welfare (Paalanen et al., 2006). The FVC data collected in 2007 and 2011 with the FFQ was used for participants aged 30 to 49 (III). Participants self-reported their consumption of daily food and drink items during the past 12 months. The reported intakes (frequency and portion sizes) of fruits (including berries, fresh and canned fruits) and vegetables (including fresh, canned and root vegetables, mushrooms, brassicas, pulses and edible bulbs) were converted into grams per day by using the Finnish National Food Composition Database (Fineli®). These amounts were summed to form a variable indicating total daily FVC (Table 3).

In Study IV, a more in-depth index, indicating an overall healthy diet, was created from the self-reported data collected with the FFQ in 2011. The index included the following food items considered favorable for health: whole grain products, fruits (excluding fruit juice), vegetables and legumes (excluding potatoes), fish, vegetable fats and oils. It also included the following food items considered unfavorable for health: red meat and meat products, sugared beverages, fried and deep-fried potatoes and desserts (including pudding, ice cream, biscuits, sweet pastry, chocolate, and candy). Dairy foods were not included in the index since the reported health effects of dairy foods depend strongly on the specific foods or beverages with which they are compared (Willett & Ludwig, 2020). Mean daily food intake was converted into grams, after which the participants were divided into quartiles based on their mean daily intake scores for each food item. The quartiles were given ascending values (0, 1, 2, and 3 points) for the favorable food items and descending values (3, 2, 1, and 0 points) for the unfavorable food items. Points were summed to create a diet quality index ranging from 0 to 27 (Table 3).

4.2.3.3 Television viewing and screen time during leisure

A self-administered questionnaire was used to collect data on daily TV time (II) and screen time during leisure (IV). In Study II, self-reported TV time during leisure was used to create TV time trajectories in adulthood from the data collected in the years 2001, 2007 and 2011. Participants were asked how much time on an average weekday and weekend day they spent watching television. From these data, mean daily TV time was calculated: ([5 × weekday] + [2 × weekend])/7 = hours of daily TV time (Table 3).

In 2011, self-reported television and video viewing time was combined with computer use during leisure to measure overall recreational screen time (IV). Participants were asked how many hours on an average day they spent using a computer and viewing television and videos during leisure. Mean daily television, video and computer time was first calculated separately ([(5×weekday) + (2×weekend)] / 7), after which the mean values of these sedentary behaviors were summed to form an index of daily screen time during leisure (hours/day) (Table 3).

4.2.3.4 Sleeping behavior

Sleep difficulties and sleep duration were self-reported in 2011 and used in Study IV. Jenkins Sleep Scale was used for assessing sleep difficulties, as it has proven to be valid and reliable (Crawford et al., 2010; Jenkins et al., 1988). The scale comprises four items on sleep difficulties which were asked from the participants: problems in falling asleep, awakenings during sleep, difficulties staying asleep, and feelings of tiredness after a normal night's sleep (Jenkins et al., 1988). If participants reported more than one symptom, their most frequent symptom was recorded as their degree of sleep difficulty. Sleep difficulty was categorized as (1) no sleep difficulty (none or one night a week), (2) moderate sleep difficulty (2-4 nights a week), or (3) severe sleep difficulty (5-7 nights a week) (Table 3).

Young adults and adults are recommended to sleep 7-9 hours per night (Hirshkowitz et al., 2015). In 2011, sleep duration was assessed by asking participants how many hours, to within the nearest half an hour, they usually slept per night (IV). A binary variable was created where one equaled meeting and zero equaled not meeting the recommended 7-9 hours of sleep per night.

4.2.3.5 Smoking and binge drinking

In 2011, participants self-reported their current smoking status (IV). The smoking status categories were: (1) non-smoker (never smoked), (2) former smoker (suspended or stopped smoking), (3) occasional smoker (less than once a week), and (4) regular smoker (once or more a week).

Binge drinking was self-reported in 2011 (IV). Both men and women were asked how often they consumed six or more units of alcohol on a single occasion. The categories for binge drinking were: (1) six times a year or less, (2) one to three times a month, (3) once a week, and (4) twice a week or more often.

4.2.3.6 Covariates

Age and sex were taken into account in the analyses. Numerous other factors potentially associated with or confounded the models, such as BMI and educational attainment, were also considered (II-IV) (Table 3). BMI was calculated as weight (kg)/height (m^2). Number of years of education of participants´ mothers was used as a proxy for SES along with participants' self-reported number of years of education. Marital status was dichotomized into being/not being in a relationship (married, in a registered relationship or cohabiting vs. unmarried, divorced, legally separated or widowed). In 2007 and 2011, total energy intake was assessed based on the FFQ (Paalanen et al., 2006) and used as a covariate when studying dietary behavior.

In Study IV, self-reported health-related behaviors in childhood, adolescence or young adulthood were used as covariates for the corresponding health-related behaviors in adulthood (Table 3). A healthy diet index was created from the 1989 data: food items defined as healthy were fruits, vegetables, fish, and vegetable fats and those defined as unhealthy were sausage dishes, sugared beverages, sweets, pastry, and ice cream. A healthy diet index was created with higher values indicating a healthier diet (range 9-54). The following health-related behaviors were also treated as covariates: screen time in 2001 (television and computer time in hours per day), smoking in 1989 (scale from 1=non-smoker to 4=regular smoker), total of binge drinking occasions in 1989 (scale from 1=none to 5=over 10 occasions), meeting the sleep recommendations in 1986 (7-9 hours of sleep/night) and feeling fatigue (scale from 1=rarely/never to 4=daily) in 1986. Sleep duration and fatigue were assessed from a subsample of the 18-, 21- and 24-year-old participants in 1986. A more detailed description of the covariates can be found in the supplementary material accompanying Study IV. Smoking status in 2001 was also used in Study II, where it was dichotomized as being / not being a daily smoker.

4.2.4 Statistical analyses

4.2.4.1 Software

Descriptive statistics were calculated by using IBM SPSS Statistics for Windows, version 24.0 (IBM Corp. Armonk, NY, USA) and reported as means and standard deviations for continuous variables and as frequency percentages for categorical variables. Independent-samples t-test was used when reporting differences between sexes for the descriptive variables.

All the other statistical analyses, including the identification of the trajectory classes and studying the associations between the trajectories and other health-related behaviors, were conducted with Mplus (Muthén & Muthén, 2017), versions 7.0 (II), and 8.0 (III, IV). Figures were drawn by using Graph Pad software from Prism (versions 8.0 and 9.0) for Windows (San Diego, California USA, www.graphpad.com), R Statistics software, or Microsoft software.

4.2.4.2 Identifying trajectories

LTPA trajectories (II-IV) and TV time trajectories (II) were identified using latent profile analysis. In Study II, both sexes were combined whereas in Studies III and IV separate LTPA trajectories were identified for women and men. In Study II, the trajectory data were arranged by year of measurement, i.e., 2001, 2007, and 2011, when the participants were aged 24-39, 30-45, and 34-49 years, respectively. In Studies III and IV, the trajectory data were rearranged: instead of the year of measurement, the data were arranged by age, i.e., at age 9, 12, 18,…, 49 years. Because the content of the LTPA questionnaires changed in 1992, overlapping items were recoded for missing values. This resulted in similar content from age 9 to 21 and from age 24 to 49 (III, IV). The distinct LTPA trajectories from childhood to middle age (ages 9-49 years) used in the present research had first been identified in a previous study (Salin et al., 2019) that formed part of the larger research project "The Role of Physical Activity in Healthy Behavior".

Error variances were assumed to be equal across classes and models with up to six classes were fitted (II-IV). Several fit indices were used to evaluate the goodness-of-fit of the models with different numbers of trajectories. The Akaike's information criterion (AIC), Bayesian information criterion (BIC), and sample-size adjusted Bayesian information criterion (ABIC) were used (II-IV). Lower values of the information criteria indicated a better fit than an alternative model with higher values. In addition, Vuong–Lo–Mendell–Rubin, Lo–Mendell–Rubin adjusted, and parametric bootstrapped likelihood ratio tests were used for determining the most suitable number of trajectories. The estimated model was compared to the model with one trajectory less, a low p-value indicating that the model with one class less was rejected in favor of the estimated model. The quality of the classification was evaluated using entropy values and average posterior probabilities for the most likely latent class membership (all ranging from 0 to 1 for both measures, the value 1 indicating perfect classification). Average posterior probabilities higher than 0.7 were considered acceptable (Muthén & Muthén, 2017; Nagin, 2005).

Missing data were assumed to be missing at random (MAR). MAR does not allow the probabilities of missingness to depend on missing data but instead on observed data (Schafer & Graham, 2002). Model parameters were estimated by using the full information maximum likelihood method with robust standard errors by imputing a value for missing responses based on the values of other responses, thereby enabling use of all the available data (II-IV).

4.2.4.3 Studying associations

In Study II, the interrelationship between the LTPA and TV time trajectories were analyzed via transition probabilities obtained from multinomial logistic regression analysis. The latent class variable of TV time was regressed on the latent class variable of LTPA and was adjusted for age, education, BMI, and smoking. Sex was allowed to be associated with the latent class variables and to moderate the association between LTPA and TV time. Differences in the sex effect on TV time across the LTPA classes were tested. The adjusted transition probabilities were calculated separately for men and women.

In Studies III and IV, the mean differences of the selected health-related behaviors across the LTPA trajectories were analyzed via the Bolck-Croon-Hagenaars (BCH) approach (III, IV). When using the BCH approach, changes in LTPA latent class membership are avoided, as the model estimates for the latent classes are not affected by the auxiliary variable (here other health-related behaviors) (Asparouhov & Muthén, 2015). The BCH weights were first saved from the latent profile analysis run with the optimal number of LTPA trajectories. BCH weights are group-specific weights computed for each participant during estimation of the latent profile model. In the second run, the BCH weights were used as training data, and a multiple group regression model was estimated. To interpret mean differences of the studied health-related behaviors across the LTPA trajectories required a Wald test p-value of <.05.

In Study III, FVC was regressed on age-specific covariates within the distinct LTPA trajectory classes, and differences in the regression intercepts (i.e., adjusted means of the health-related behaviors) across the trajectory classes were studied. The models were adjusted for participant's BMI, education level, and total energy intake. In Study IV, three different models were analyzed: one unadjusted model (model 1) and two adjusted models (models 2 and 3). In model 2, the mean values of the health-related behaviors were adjusted for age, BMI, education level, marital status, and total energy intake. Total energy intake was used as a covariate only when studying the mean values of dietary behavior across the LTPA trajectories. In model 3, the previous corresponding health-related behavior was also used for adjusting the model. When adjusting models 2 and 3, the mean values of the health-related behaviors were regressed on the above-mentioned covariates for the distinct LTPA trajectories. Differences in the regression intercepts were studied across the trajectory classes. Models were adjusted using standardized values of the covariates. In Study IV, a measure of effect sizes concerning mean differences in the health-related behaviors across the LTPA trajectory classes was provided by calculating Cohen's d (Cohen, 1992) and Cohen's h (Cohen, 1988, pp. 179-213). Effect sizes were interpreted as small (0.20-0.49), medium (0.50-0.79), and large (⩾0.80).

4.3 Quality assessment

To enhance reporting quality, the systematic review (I) was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Moher et al., 2015), and applying the PRISMA checklist. Studies III and IV were conducted according to the Strengthening the Reporting of Observational Studies in Epidemiology–nutritional epidemiology (STROBE-nut) checklist (Hörnell et al., 2017). For ensuring the quality of the latent profile analyses for identifying the LTPA trajectories, the Guidelines for Reporting on Latent Trajectory Studies checklist (Van de Schoot et al., 2017) was applied with modifications (III, IV).

Sensitivity analyses were performed in Study IV because the sample sizes dropped, especially in model 3. The results of the sensitivity analyses closely resembled those of the main analyses. More detailed results of the sensitivity analyses are presented in Study IV.

5 RESULTS

5.1 Systematically reviewed physical activity trajectory studies (I)

5.1.1 Description and quality of the reviewed studies

Altogether 27 articles, published between the years 2004 and 2018 and studying the populations of high-income countries, met the inclusion criteria for studies identifying longitudinal PA trajectories in the general population during different life phases (Figure 4). The two authors assessing the quality of the studies had 90% initial agreement and after dialogue a full consensus was reached. Sixteen studies were rated as of good quality, eleven as fair, and none as poor. The reviewed studies seemed to meet the methodological quality criteria for observational studies rather well, as compared to the criteria for reporting on trajectory modeling (see quality analyses in Study I). This points to the lack of consistency between studies in approaches to identify trajectories with finite mixture modeling.

Participant age at baseline in the 27 included studies varied between 4 to 96 years, and hence children, adolescents, adults, or older adults were studied. To build a synthesis, the reviewed studies were classified by participant age into three groups: youngest, middle and oldest. The youngest group consisted of children, adolescents and young adults, and the oldest group of late middle-aged and older adults. The middle group was slightly mixed, with the baseline in childhood, adolescence, or adulthood and, in some studies, the follow-up time continued into old age. However, the factor uniting these studies was that the study sample mainly comprised adults. The youngest group contained eleven articles and the middle and oldest groups each contained eight. More detailed information on the included studies can be found in the extraction table in the original publication (I).

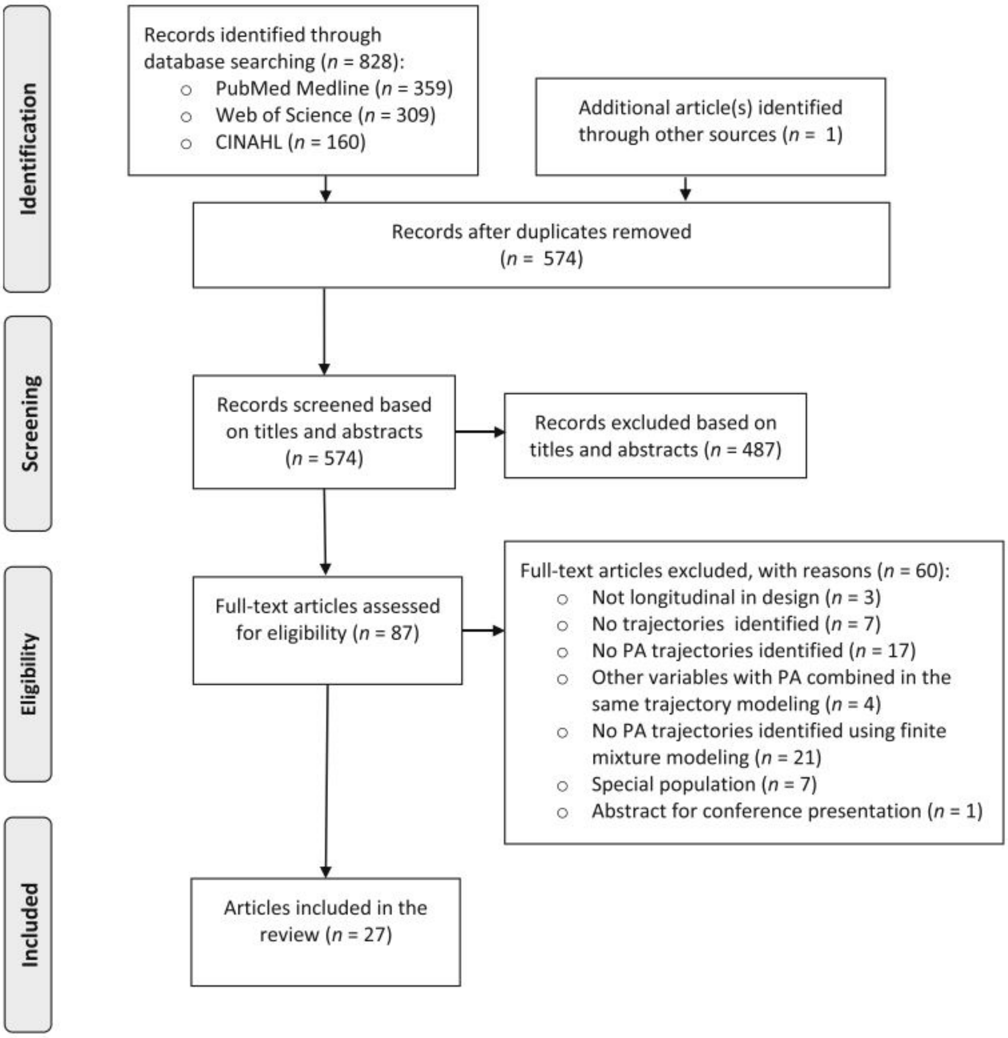
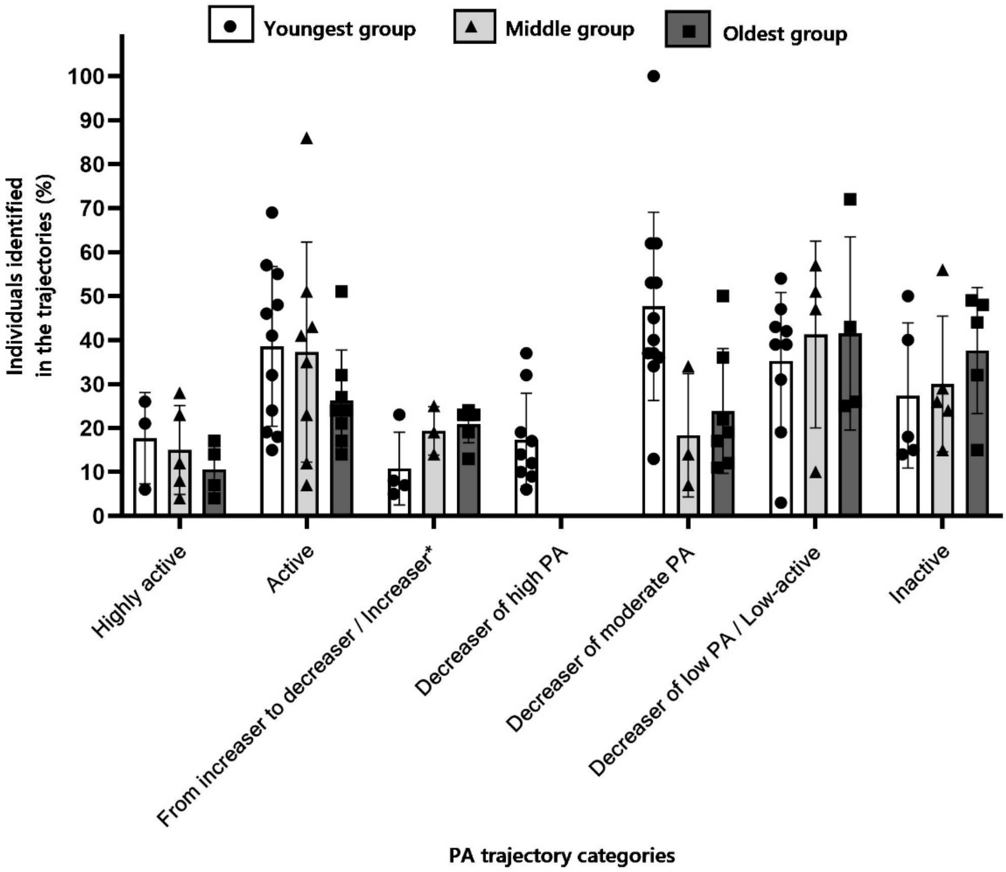


FIGURE 4 Flow chart (originally published in Study I).

5.1.2 Physical activity trajectories in the reviewed studies (I)

The broader term "PA trajectories" was selected to refer to all the different types of PA, sport participation and exercise trajectories identified in the reviewed studies. Six studies measured PA with objective measures and 23 with self- or parental reports. Most commonly, three to four PA trajectories were identified, thereby demonstrating that PA does not develop similarly across individuals. Most studies (12/27 studies) examined both sexes in the same trajectories while others identified trajectories separately for men and women (8/27) or only studied men (2/27) or women (5/27).

Each PA trajectory identified from the reviewed studies was classified under the PA trajectory category that best described its type, meaning its name, shape, and context. The categories derived from the studies were Highly active, Active, Inactive, Increaser, From increaser to decreaser, Decreaser of a high PA level, Decreaser of a moderate PA level, and Decreaser of a low PA level or low-active. The prevalence of the different PA trajectories in the different PA trajectory categories across the three age groups and the proportion of individuals identified in each trajectory is shown in Figure 5. A broader forest plot with study specific trajectories can be found in Additional file 4 in Study I.



The bars represent the mean proportions and the dots the proportions of individuals in each trajectory identified in the reviewed studies. Previously identified trajectories used in later publications are not reported twice in the figure. *The category "From increaser to decreaser" was used in the youngest group only and the category "Increaser" applies in the middle and oldest groups.

FIGURE 5 The proportions of individuals identified in the different physical activity trajectory categories across the three age groups in Study I.

Differences and similarities in trajectory class membership and trajectory shape between the age groups were detected (Figure 5). The proportion of participants identified in the highly active or active trajectories was generally higher in the youngest group when compared to the middle and especially oldest group. While the proportion of participants in trajectories assigned to the inactive or low-active categories was rather high at all ages, an increasing tendency towards inactivity and low activity was found with age. Analysis of the shapes of the trajectories showed that physical inactivity and low-activity were more persistent behaviors than high or moderate PA.

Trajectories describing change in PA level over time were more prevalent among children and adolescents, whereas trajectories describing persistent physical activity, low activity or inactivity were more prevalent in adulthood. More than half of the trajectories identified in the studies on the youngest group showed a downward trend in PA level, which was often initiated already in childhood. Analysis of the shapes of the trajectories showed that mean age at the start of the decline was 7.7 years in the studies using objective measures of PA, 9.6 years in the studies using self-reports of PA and 10.8 years in the studies using self-reports of sport participation. However, the decline in trajectories described with decreasing PA level during childhood or adolescence had not yet reached the level of those in the inactive trajectories. The studies on older adults, however, showed decreasing trajectories of PA that eventually fell to the level of the inactive or low-active trajectories. At the same time, no PA trajectories with a consistently increasing trend were detected in the youngest group. However, three studies in the middle and five in the oldest group also identified PA trajectories with an increasing trend.

5.1.3 Factors associated with the physical activity trajectories in the reviewed studies (I)

While the identification of distinct PA trajectories in the general population was the factor connecting the systematically reviewed studies, the main aims of the studies varied widely. For the most part, the studies explored the potential associations of the identified PA trajectories with a variety of predictors, determinants, and outcomes. Sociodemographic characteristics, SES, family or social support, health behaviors, and health-related variables were the factors most frequently studied in relation to the PA trajectories. Findings from multiple studies confirmed that men more often than women and participants with higher rather than lower SES were in the higher PA level trajectories rather than lower (Table 4).

Associations between other health-related behaviors and the diverse PA trajectories were examined in several studies. Smoking cessation and non-smoking were associated with a tendency to an increase in the level of PA or a persistently higher level of PA, whereas current smoking was generally associated with a decreasing level of PA, low activity, and inactivity. In contrast, higher alcohol consumption was associated with the likelihood of being at least moderately active or increasingly active rather than inactive or decreasingly active. In adolescence, persistent PA was associated with a decreasing amount of TV time and a decline in PA level with an increase in TV time. Dietary behavior and PA trajectories also seemed to be related: older adults with higher FVC were more likely to be identified in the active than low-active trajectory. The number of studies finding associations between different PA trajectories and the factors of interest are presented in Table 4.

TABLE 4 Number of studies finding associations between the factors of interest and the different types of physical activity trajectories across age groups.

	Highly active / Active			Low-active / Inactive			Increaser of PA			Decreaser of low, moderate or high PA		
	Age groups			Age groups			Age groups			Age groups		
Factors of interest across PA trajectories	Y.	M.	O.	Y.	M.	O.	Y.	M.	O.	Y.	M.	O.
Higher education, academic performance, income or occupational status*	4	1	6					1	1		1	
Lower education, income or occupational status*					3	1					2	
Living in urban area	1											
Living in rural area	1											
Being single or never married						2						
Having two parents (vs. single parent) at home	1											
Having children											1	
Parental PA	3											
Male gender	5	2	1									
Being Caucasian or White	2											
Being non-Caucasian or Black				1		1				1		
Current smoking or alternative tobacco use	1			1	2	4				2	1	
Higher likelihood of alternative tobacco use	1									1		
Smoking cessation or non-smoking	2							1				
Greater alcohol consumption		1	1					1	1		1	
Decreasing television viewing time	2											
Increasing television viewing time										1		
Lower fat intake			1									
Higher consumption of vegetables and fruits			1									
Better overall health profile	1		2									
Greater bone strength	1											
Higher likelihood of over-weight, obesity or unfavourable changes in body composition					1	3				1		2
Chronic diseases**					2	4						1
Good physical functioning			2						1			
Having physical difficulties or disabilities						3						1
Low self-rated health						2						
Low mortality rate			2									
Depressive symptoms			1			3						1

*Income and educational level of parents in the youngest group. **E.g., arthritis, arthrosis, bronchitis, coronary artery disease, chronic obstructive pulmonary disease, or high blood pressure. *PA* physical activity; *Y* Youngest group; *M* Middle group; *O* Oldest group.

5.2 Development of leisure-time physical activity and associated health-related behaviors in the YFS (II-IV)

5.2.1 Leisure-time physical activity trajectories in the YFS (II-IV)

In this dissertation, two sets of LTPA trajectories were identified: those comprising adults alone (II), and those including children, adolescents, and adults (III, IV). In Study II, the solution with four trajectory classes (adjusted for age and sex) provided the best model fit (see Table 2 in II). However, since the size of the persistently very highly active class was small, the three-class solution was considered more suitable. The LTPA trajectories identified in the three-class solution were persistently highly active, persistently moderately active, and persistently low-active (Figure 6). In Studies III and IV, the five LTPA trajectory solution showed the best model fit for women and the four LTPA trajectory solution the best fit for men (see Table 2 in III). Persistently active, persistently low-active, decreasingly active, and increasingly active trajectories were identified in both sexes, with an additional inactive trajectory in women (Figure 7).

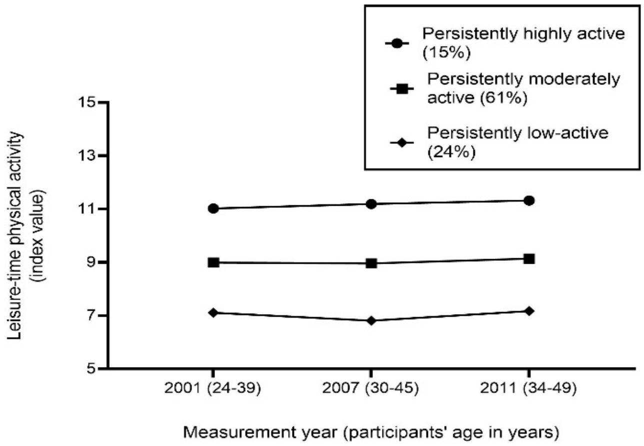


FIGURE 6 Leisure-time physical activity trajectories in adulthood including both sexes (n=2886).

The LTPA trajectories identified only for adults aged 24 and older were rather stable (Figure 6) (II) whereas change – an increase or decrease in LTPA – was also observed in the trajectories identified from childhood to middle age (Figure 7) (III, IV). The continuously changing tendency in LTPA level in women identified in the increasingly active trajectory (15%) and in men in the decreasingly active trajectory (16%) was especially clear. Thus, the trajectories labelled as increasingly and decreasingly active differed in shape between women and men. The increase in PA was initiated in adolescence (around age 15-18) in both sexes, but while the increase continued until the end of the study period for women, the increase occurred only during young adulthood (ages 18–24) in men. Nonetheless, even this shorter period of increasing LTPA separated the shape of the trajectory from the shapes of the other trajectories. At the same time, the decreasingly active trajectories showed the opposite development: while the decrease in LTPA continued until the end of the study period in men (initiated at the age of 12), it occurred only during young adulthood (ages 18–27) in women.

The biggest changes in LTPA were observed during childhood, adolescence, and young adulthood (Figure 7) (III, IV). After age of 24, the trajectories seemed to stabilize: the five trajectories identified for women merged into three trajectories when the increasers reached the level of the persistently active women and the decreasingly active women reached the level of their low-active peers, while the trajectory of the inactive women remained rather stable throughout the study period. Eventually, in middle age, the decreasingly active men seemed to fall to the level of their low-active peers, which meant the merging of these trajectories. This merging of trajectories explains why only stable LTPA trajectories were observed in Study II.

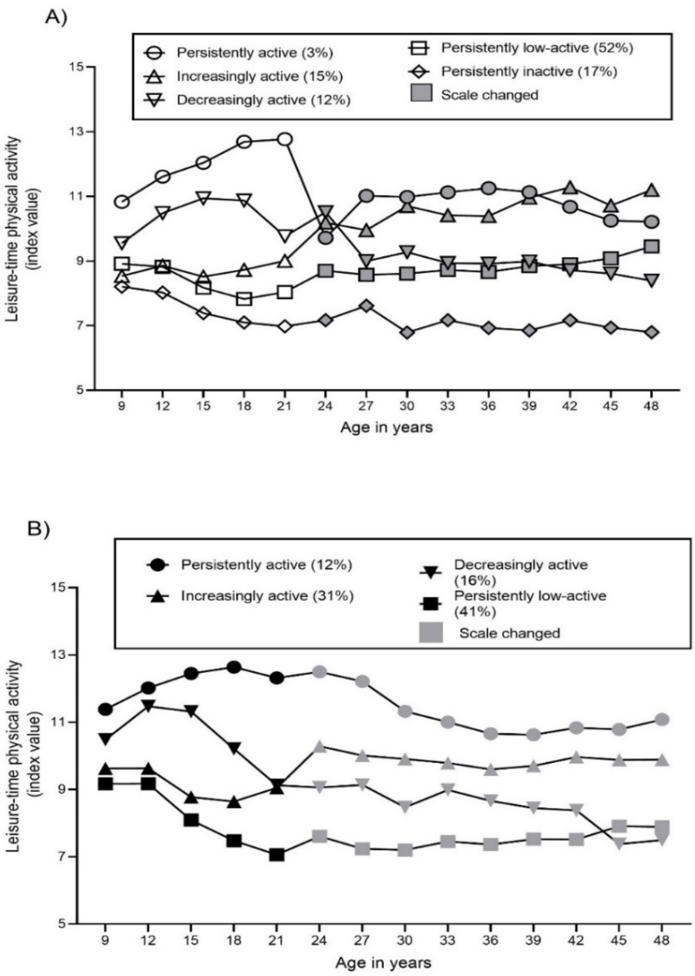


FIGURE 7 Leisure-time physical activity trajectories from childhood to middle age for A) women (n=1809 in III; n=1813 in IV) and B) men (n=1727 in III; n=1740 in IV). (Originally published in Salin et al., 2019.)

5.2.2 Health-related behaviors across the leisure-time physical activity trajectories in the YFS (II-IV)

Some of the studied behaviors, these being dietary behavior, TV time and screen time during leisure, smoking, and sleep difficulties, differed by LTPA trajectory class membership (II-IV) while other behaviors (binge drinking and having the recommended duration of sleep) did not in either women or men after adjusting the models (IV). The associations between the LTPA trajectories and other health-related behaviors were partly explained by sex, age, BMI, marital status, education, total energy intake and previous similar behavior (II-IV). The observed associations were usually stronger in women than in men (IV).

Of the studied behaviors, dietary behavior showed the strongest associations with the different LTPA trajectories (Figure 8, Appendix 1). After adjusting the models, the poorest overall diet in adulthood (IV) and the lowest FVC from childhood to middle-age (III) were found among the participants identified in the least active trajectories (the inactive trajectory in women and the low-active in men) when compared to the increasingly or persistently active trajectories ($p<.05$) (Figure 8; see Table 3 in III). The increase in FVC closely paralleled that of the increase in LTPA and, reciprocally, the FVC of the decreasingly active participants fell to the level of the persistently inactive women and low-active men as they reached adulthood ($p<.05$) (see Figures 2 and 3 in III).

Four TV time trajectories were identified for adults (II): consistently low ($\leqslant$ 1 h/d, 38.6%), consistently moderate (2 h/d, 48.2%), consistently high ($\geqslant$3 h/d, 11.7%), and consistently very high ($\geqslant$5 h/d, 1.5%). The last two trajectory classes were combined to form a "high" trajectory class in order to further analyze an interpretable model (II). The probability of the high TV time was higher among the persistently low-active adult women than among their highly active peers ($p<.05$) (See Figure 1B in II). Before adjustments, total screen time during leisure also seemed to be higher among the inactive women than peers in the persistently, decreasingly, and low-active trajectories (Appendix 1) (IV). However, the associations between screen time and LTPA in women disappeared after all adjustments (Figure 8) (IV). The persistently low-active adult men had a higher probability of low TV time than their persistently active peers ($p<.05$) (See Figure 1A in II). At the same time, men identified in the increasingly active trajectory had lower mean leisure screen time in middle-age than their persistently low-active and persistently active peers (Figure 8) (IV).

In the fully adjusted models, women and men identified in the persistently inactive or low-active trajectories smoked more frequently than their increasingly active (women and men) or persistently active (men only) peers (Figure 8). In the unadjusted model, the persistently inactive women binge drank more frequently than the women in the other trajectories but after adjustments, binge drinking did not differ across the LTPA trajectories in either sex (Figure 8, Appendix 1).

The strongest associations between the LTPA trajectories and sleep difficulties were detected in the fully adjusted model for women aged 42-49 years (Figure 8). Sleep difficulties were more prevalent among the persistently inactive women than among their increasingly, decreasingly, and persistently active peers. Additionally, the low-active women reported more sleep difficulties than the increasingly and persistently active women. No differences in the probability of having the recommended 7-9 hours of sleep was observed between the LTPA trajectories in either sex or between sleep difficulties and LTPA trajectories in men (Figure 8).

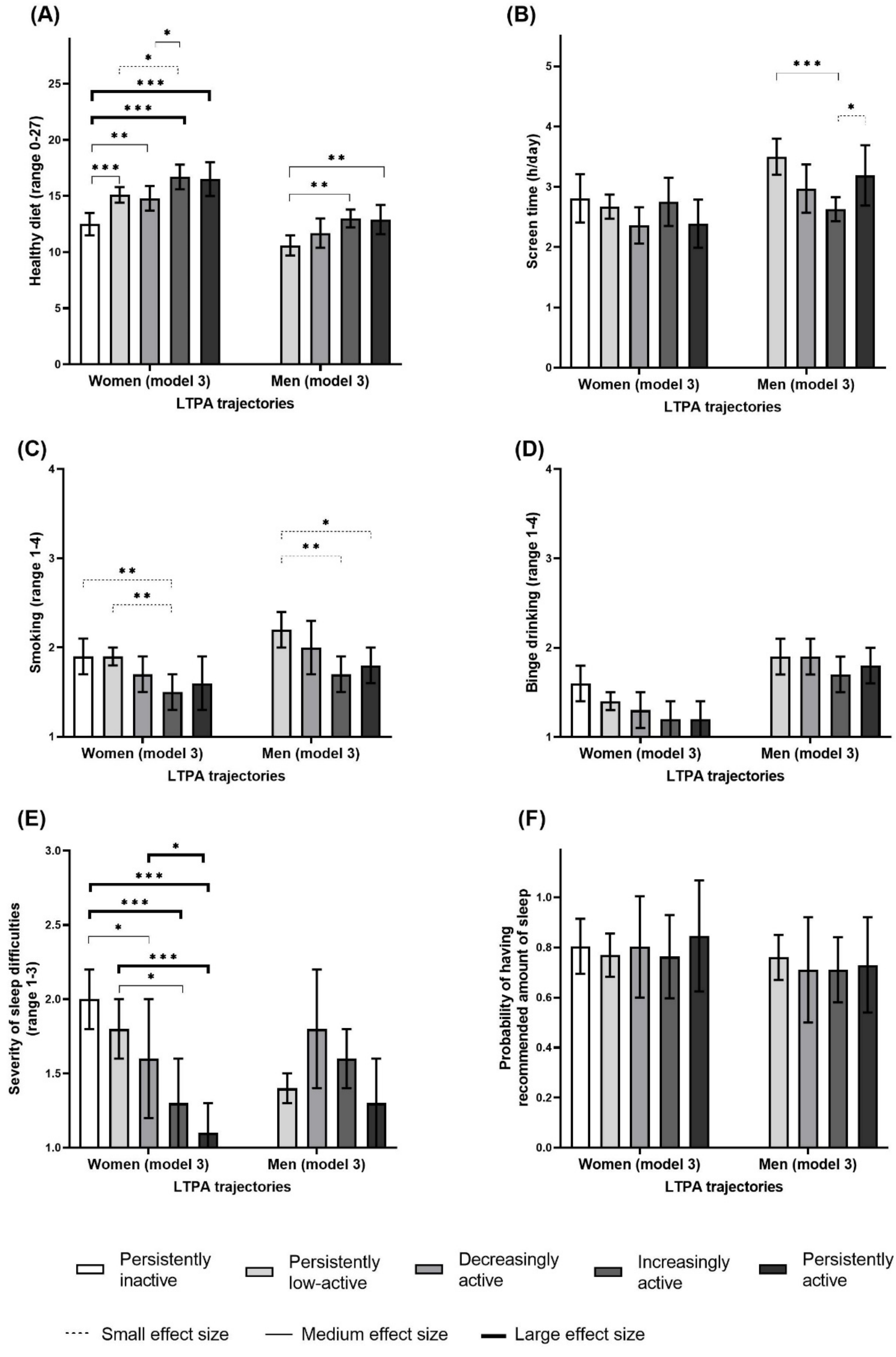


FIGURE 8 Mean values, 95% confidence intervals, p-values, and effect sizes for each health-related behavior across the leisure-time physical activity trajectories in the fully adjusted model (model 3) for women and men aged 33 to 49 years.

Legends for Figure 8 on previous page: A=healthy diet; B=screen time; C=smoking; D=binge drinking; E=severity of sleep difficulties; F=probability of having the recommended amount of sleep; Model 3 was adjusted for age, body mass index, education, and marital status and, in addition, diet was adjusted for total energy intake. Each behavior was also adjusted for the corresponding earlier behavior: diet assessed in 1989, screen time in 2001, binge drinking in 1989, smoking in 1989, fatigue in 1986 and sleep duration in 1986. Significant mean differences in each health-related behavior across the LTPA trajectory classes are marked with an asterisk (* = p<.05; ** = p<.01; *** = p<.001) and small (0.20-0.49), medium (0.50-0.79), and large (⩾0.80) effect sizes with different types of lines. *LTPA* Leisure-time physical activity.

6 DISCUSSION

6.1 Summary of the main findings

1. In the YFS data (III, IV), four different LTPA trajectories from childhood to middle age were identified among men and five among women. These were persistently active, persistently low-active, decreasingly active, and increasingly active trajectories for both sexes and an additional inactive trajectory for women (III, IV).

2. Trajectory modeling yielded novel data on inter- and intra-individual changes in PA during the life course. Diverse trajectories of decreasing PA, often starting in childhood, were identified among children and adolescents in particular. Trajectories of increasing PA were identified among adults (I, III, IV).

3. Trajectory modeling further confirmed the persistence of inactivity and low-activity when compared to higher activity (I, III, IV), the tendency of PA behavior to stabilize with age (I-IV), the relatively high prevalence of inactivity and low-activity throughout the life course (I, III, IV), and the increase with age in the proportion of inactive individuals (I).

4. The men and especially women in the persistently active and increasingly active trajectories had a healthier diet (III, IV), lower smoking frequency and less sleep difficulties (women only) when compared to their low-active or inactive peers after adjusting the models (IV). The associations of screen and TV time with the LTPA trajectories were ambiguous (II, IV). After adjustments, neither sleep duration nor binge drinking differed across the LTPA trajectories in middle age (IV).

6.2 Distinct physical activity trajectories during the life course

The finding that several PA trajectories, usually three or four, existed within different study populations (I-IV) clearly indicates that PA does not develop uniformly across individuals. While longitudinal studies have reported PA to track largely at a low, and at best moderate, level (Hayes et al., 2019; Malina, 2001b; Telama, 2009), the development of PA in individuals whose PA does not track over time has remained unclear. The present PA trajectory studies contributed new knowledge by identifying distinct pathways describing also changes in PA both between and within individuals during the life course (I-IV).

6.2.1 Leisure-time physical activity developed diversely in Finnish population

In this study examining Finnish population, persistently active and low-active, and decreasingly and increasingly active LTPA trajectories were identified in both sexes, with an additional persistently inactive trajectory in women, from childhood to middle age (III, IV). Three stable LTPA trajectories (low, moderate, and high LTPA) were also identified when adults only were studied (II). Comparison of the shapes and number of the LTPA trajectories identified from childhood to middle age (III, IV) and those identified in adulthood (II) confirmed the findings of previous longitudinal tracking studies showing that PA behavior, especially low PA, tends to stabilize with age (Telama, 2009). Thus, the contours of the low-active and inactive trajectories indicated the greater permanence of these behaviors. As expected, these findings supported Rovio et al. (2018), who also identified LTPA trajectories from childhood to mid-age (9-49 years) in the YFS data, although not separately for men and women (sex was studied as a determinant). Rovio et al. (2018) found five LTPA trajectories: persistently active (7%), decreasingly active (14%), increasingly active (14%), persistently low active (51%), and persistently inactive (15%).

Higher proportions of the YFS population were identified in the persistently low-active or inactive trajectories than in the persistently active trajectories (III, IV). This finding supports the high prevalence of insufficient PA previously observed in Finland (Borodulin & Wennman, 2019; Kämppi et al., 2018). Even though earlier PA level has been found to predict a similar level of activity in later life (Borodulin et al., 2012; Telama, 2009), the low PA level observed in childhood for the women in the increasingly active trajectory (15%) in this study did not predict low-activity through-out the life course. In fact, increasingly active women formed the most active trajectory group after age of 40. Among men, in contrast, a continuously decreasing LTPA trajectory was identified in which the decrease was started in adolescence. These men became inactive despite starting out in childhood with a relatively high level of LTPA (III, IV). A recent meta-analysis confirmed this gender difference by showing that the decline in PA during the transition from adolescence to adulthood (age 13-30 years) was greater in men than women (Corder et al., 2019).

While the current study did not focus on the characteristics of the individuals identified in the different trajectories in YFS (II-IV), it is important to understand what factors determine trajectory class membership in order to target PA promotion effectively to right key groups. In the YFS, Rovio et. al. (2018) examined the characteristics of the members of the different LTPA trajectories. Their findings can be assumed to apply to the LTPA trajectories identified in this dissertation (III, IV), as the data used were the same. At the age of 24, having children was found to be associated with a decreasing LTPA trajectory (Rovio et al., 2018). Another study using the YFS data examined the associations of major life changes with the number of daily steps over a 4-year period among 34-49 year-old adults (Salin et al., 2021). Women who had a child and men who divorced during the four-year study period showed a decrease in nonaerobic steps (steps lasting less than 10 min without interruption) while women who recoupled decreased their total number of steps (Salin et al., 2021). In contrast, in a British study, having a child was associated with a reduction in PA in men but not in women (Werneck et al., 2020). Thus, changes in relationships or in family structure may have an effect on changes in LTPA – a finding also supported in the present review (I). Other hitherto un-examined life events may potentially explain changes in LTPA trajectories. For example, change in employment status and change in residence have been associated with PA (Allender et al., 2008).

Previously, persistently high SES and upward social mobility have been found to be to associated with increases in self-reported PA in adults (Cleland et al., 2009). This finding corroborated that of the present review in which higher education, income or occupational status was more likely to be present among the individuals identified in the persistently or increasingly active trajectories than among those in the inactive, low-active or decreasing trajectories (I). In Finland, differences in PA level by education increased between the years 1982-2012 (Borodulin, Harald, et al., 2016), especially with regard to LTPA: the highest LTPA levels were observed among the highest educated and the lowest among the least educated. In the YFS, Rovio et al. (2018) found that over one-third of the persistently and increasingly active children (12 years of age) had a grade point average of over 8.5 (in Finland, school subjects are graded on a scale from 4 to 10) as compared to only 14% of the inactive individuals ($p<.001$). In adulthood, high education was associated with both the increasingly and decreasingly active trajectories (Rovio et al., 2018).

It is important to bear in mind that the present study population (III, IV) was drawn from the Finnish population aged 9 to 49 years of age between the years 1980 and 2011. Trends in PA behavior in Finland (Borodulin, Harald, et al., 2016; Laakso et al., 2008) and worldwide (Hallal et al., 2012) have changed during these decades. Trends in the level of PA in high-income countries have shown LTPA to have increased in adults whereas occupational PA has decreased (Hallal et al., 2012). Finland is no exception: high occupational and high active transport PA decreased between the years 1982-2012 (Borodulin, Harald, et al., 2016). These trends reflect the reduction in physical movement at work, at home, and in travel (Church et al., 2011; Ng & Popkin, 2012), especially, by the recent advances in digital technology that have led to major reductions in energy expenditure in performing many tasks (Ng & Popkin, 2012). Thus, increases in LTPA are important from the perspective of adopting a physically active lifestyle in today's technology-based and highly automated society.

LTPA, particularly organized sport, showed a rising trend among Finnish adolescents aged 12-18 years over the period 1977–2007 (Laakso et al., 2008). While total PA remained rather stable among Finnish adults aged 24-65 years during the period 1982-2012, an increase in general LTPA levels was observed in both women (from 12% to 27%) and men (from 21% to 33%) (Borodulin, Harald, et al., 2016). The promotion of PA in Finland during recent decades might have played a role in the trend towards increased LTPA (Vuori et al., 2004). The overall increase in LTPA has been greater in Finnish girls than boys (Laakso et al., 2008) and, among adults, greater in women than men, the statistics indicating that as large a proportion of Finnish women as men were active during leisure in the start of the 21st century (Borodulin et al., 2008). In the present data, a bigger proportion of Finnish men than women (12% vs. 3%) were in the persistently active LTPA trajectories during middle age (III, IV). However, when the increasingly active women (15%), whose LTPA level reached that of the persistently active trajectory, are taken into account, the gender difference disappears (III, IV).

Increased gender equality has been found to associate with higher LTPA in women (Balish et al., 2016). One explanation behind the faster increase in LTPA in women than in men may be the actions taken in Finland to improve gender equality in various societal domains (Statistics Finland, 2018). This might have had an indirect effect on use of leisure time owing to growing awareness, for example, that household chores and taking care of children are not the responsibility of women alone. Globally, however, PA has been found to be less prevalent in women than men (Hallal et al., 2012; Ozemek et al., 2019; Sallis et al., 2016), the data often being based on national surveys that mostly focus on LTPA (Ozemek et al., 2019).

6.2.2 Decline in PA started in childhood

At least one, but usually several, trajectories describing a decline or incipient decline in PA were identified among children and adolescents in the different study populations (I, III, IV), an observation also verified by the most recent PA trajectory studies using objective methods (Oh et al., 2021; Pate et al., 2019). Knowledge, not only on the previously reported general tendency of PA decline in childhood or adolescence (Corder et al., 2019; Jago et al., 2008; Laakso et al., 2008), but also on whether the decline in PA is from a high to moderate or from a low to inactive level is of value from a public health perspective in helping to identify the groups at highest risk for becoming inactive. In other words, given that PA bouts of any length add to the health benefits associated with PA (Physical Activity Guidelines Advisory Committee, 2018), a decrease to a moderate level of activity would not be as harmful to health as a decrease leading to inactivity.

The reviewed studies (I) using self-reported measures of PA (focusing mainly on LTPA or sport participation) found the level of PA to decline around

10 years of age (Findlay et al., 2010; Kwon, Lee, et al., 2015; Rovio et al., 2018) whereas the studies using objective measures of PA (focusing mostly on MVPA and total PA) found the corresponding age to be as young as around 7 to 8 (Farooq et al., 2017; Janz et al., 2014; Kwon, Janz, et al., 2015). The age difference found between the two measurement types might be explained by the drop-out vs. drop-off phenomenon: dropping out from organized PA or sport club training often occurs during the teenage years whereas drop-off refers to the decline observed in overall PA, best measured objectively (Aira et al., 2013).

Based on novel systematic reviews, longitudinal studies, and evidence from the International Children's Accelerometry Database, MVPA indeed starts to decline, and sedentary behavior to increase, already from around the age of school entry (Reilly, 2016). Interestingly, a Swiss study using objective measures of PA, and identifying one mean trajectory of total PA and MVPA for both sexes, showed that total PA and MVPA continued to increase among preschoolers aged 2-7 years (Schmutz et al., 2018). This underlines the importance of targeting future PA promotion to transition phase from preschool to school. Since PA was higher among preschool-aged children with active parents (Hinkley et al., 2008), possible future PA interventions could be effective if aimed at families. A previous study using the YFS data also found the children identified in the low-active and inactive trajectories being less likely to have a physically active parent than peers in the other trajectories ($p<.001$) (Rovio et al., 2018).

However, several other factors also merit consideration when seeking to tackle the global challenge of PA decline in childhood and adolescence. For example, children and adolescents report different factors as barriers and motivators for PA. Motives for PA and sport for children under 15 years of age included encouragement, parental, friend and teacher support, and possibilities for experimentation, while barriers were competitive sports and highly structured activities (Allender et al., 2006; Sterdt et al., 2014). It is noteworthy that children have been found to enjoy participation in sport or PA more when they are not forced to compete and win (Allender et al., 2006). In fact, pressure to compete can cause children to experience psychological stress disorders and anxiety (Choi et al., 2014). This highlights the importance of children having a task-involved, rather than ego-involved goal perspective (Nicholls, 1984), in PA and sport hobbies as well as in physical education lessons. Usually, the older children get, the more competitive sport club participation becomes, which may be the reason for drop-out.

Among adolescents, reasons for dropping out from sport participation include perceptions of competence, social pressures, lack of enjoyment, competing priorities and physical factors (maturation and injuries) (Crane & Temple, 2015; Slater & Tiggemann, 2010). Identity conflicts have also been reported to hinder participation (Allender et al., 2006). While managing weight and body shape (Allender et al., 2006) and staying fit (Sirard et al., 2006) have been found to be motivators of PA among adolescent girls, they may nevertheless drop out from sport due to body image issues, or feelings of incompetence (Slater & Tiggemann, 2010). These findings have important implications for physical education teacher training and coach training programs.

To prevent the decline in PA and help children and adolescents to maintain their PA level, also environmental issues should be addressed on the national policy level. Among children, time spent outdoors and school PA-related policies (e.g. outdoor activities, access to equipment, play structures in school) have been observed to be the most consistent positive environmental correlates of PA (Ferreira et al., 2007). At the same time, the number of roads to cross, traffic density or speed, and local crime and area deprivation have been found to be negatively associated with children's participation in PA (Davison & Lawson, 2006). Overall, preventing drop off and drop out from PA or sport participation in childhood and adolescence may be of considerable importance since it can hinder or postpone the onset of inactivity.

6.2.3 Trajectories of increasing physical activity identified in adulthood

While PA surveillance, research and policy adaptation have improved during the last decade, policy implementation remains in need of further development as, globally, an overall increasing trend in PA levels has not yet been detected (Sallis et al., 2016). However, on the individual level, trajectory groups with increasing PA have been identified (range: 4-31%) in eight of the trajectory studies included in the present systematic review (I), in a few trajectory studies published since the review (Aggio et al., 2018a; Saint-Maurice et al., 2019; Sanchez-Sanchez et al., 2020; Sandhu et al., 2020), and in the current study, in which trajectories were identified from childhood to mid-age (III, IV). The identification of trajectories showing an increase in PA levels was a promising finding (I, III, IV), indicating that, despite the potential inactivity or decrease in PA in childhood or adolescence, a physically active lifestyle does not necessarily need to be initiated in youth.

The increasing trend in PA level was most often observed among young adults, middle-aged adults, and older adults whereas among children and adolescent a decline followed an initially observed increase in PA (I). In studies examining older adults over 70 years of age, no increasing PA trajectories were identified (I). Thus, if an increasing PA trajectory was observed among older adults, it concerned slightly younger older adults around the time of retirement (I). Retirement has been found to be a life phase favoring an increase in PA (Hirvensalo & Lintunen, 2011; Touvier et al., 2010), and hence potentially a good time for PA interventions. Irrespective of the difficulty of increasing PA, even a modest increase in PA or maintaining a moderate PA level without necessarily reaching the recommended PA level may have high importance for health and reducing mortality risk (Physical Activity Guidelines Advisory Committee, 2018). Aggio et al. (2020) observed a lower mortality risk among older adults, not only among those in the highly active trajectory, but also among those in the modest PA trajectory, which for inactive older adults may be a more achievable objective than high PA. In addition, current PA, rather than previous PA level, has been found to be a stronger indicator of mortality risk (Aggio et al., 2020; Laddu et al., 2018). Furthermore, recent PA trajectory study showed that those with an increasing PA trajectory during late life were more likely to have lower incident disability rates than peers in the low decreasing PA trajectory, despite of a similar baseline level of PA (Sanchez-Sanchez et al., 2020). Thus, from the standpoint of mortality and health, it is better to embark on a physically active lifestyle late, for example during young, mid or old adulthood, than never.

Groups who show increasing levels of PA should be studied in more detail in order to better understand these individuals and the diverse factors and reasons explaining why they are able to increase their PA level. Social support, health benefits and enjoyment have been reported to motivate physically activity in older adults (Allender et al., 2006). Meanwhile, mastery and competition have more often been found to motivate adult men to engage in PA (Molanorouzi et al., 2015), whereas adult women are motivated more by external appearance and physical condition (Molanorouzi et al., 2015). A study examining adult men reported the barriers to PA to be logistic (e.g., costs), cognitive-emotional (e.g., feelings of inferiority), social (e.g., family situation), and lack of time (Ashton et al., 2015). In order to get people to increase their PA level, the right motivators should be aimed at the right key groups and, if possible, barriers removed.

6.2.4 High prevalence and stability of inactivity and low activity increased with age

As expected, this dissertation further confirmed previous findings on the rather high proportion of inactive or low-active individuals across the lifespan, irrespective of age and the generally declining trend in PA levels with age (Hallal et al., 2012; Hayes et al., 2019). Older adults (>80 years) are more likely than younger adults (18-29 years) to be physically inactive (Sallis et al., 2016). In 2015, the prevalence of inactivity was reported to be 55% among older adults versus 19% among younger adults (Sallis et al., 2016). This is understandable given the general decline in health (Hirvensalo & Lintunen, 2011; Xue et al., 2012) and physical functioning in old age (Artaud et al., 2016; Laddu et al., 2020; Physical Activity Guidelines Advisory Committee, 2018).

However, being physically active could be the factor preventing or ameliorating some detrimental changes in health and performance. The findings from the present systematic review showed that older adults with higher PA had better physical functioning than less active peers (I). A higher or increasing rather than lower or decreasing PA trajectory has been found to correlate also with reduced mortality risk (Aggio et al., 2020; Sanchez-Sanchez et al., 2020; Xue et al., 2012), hospitalization, and lower rates of incident and worsening disability (Sanchez-Sanchez et al., 2020). These findings highlight the importance of targeting PA interventions to older adults.

The present findings also supported earlier observations that inactivity and low-activity are more persistent behaviors than activity, and that PA levels usually stabilize with age (Telama, 2009). Many of the most recent trajectory studies (Inada et al., 2021; Laddu et al., 2018; Pate et al., 2019; Saint-Maurice et al., 2019; Sanchez-Sanchez et al., 2020; Sandhu et al., 2020) corroborate this observation.

Thus, PA trajectory studies indicate that it is easier to adopt and maintain an inactive rather than active lifestyle. This presents a major challenge for public health and behavioral change interventions aiming to help people adopt a physically active lifestyle. Adopting a new behavioral pattern is not easy (Geller et al., 2017). This is especially true of PA, which has been suggested to be a behavior that cannot truly become habitual (Hagger, 2019). Habits are not defined simply as frequent behaviors but as specific behavioral responses that are automatically activated by a defined set of cues with limited conscious awareness of goals (Verplanken, 2006). Habitual PA, while it can be initiated, is governed by more intentional, reasoned processes (Hagger, 2019). Engaging in PA requires effort, which poses a challenge to reverse physical inactivity to activity.

6.3 Certain health-related behaviors associated with leisure-time physical activity trajectories

This dissertation sought to ascertain the role of LTPA in adopting other health-enhancing behaviors (II-IV). Those identified in the persistently, and especially increasingly, active life course trajectories had accumulated several health-enhancing behaviors: following a healthy diet, refraining from smoking, enjoying less disturbed sleep (women only), and having lower screen time (increasingly active men only) (III, IV). At the same time, those in the inactive or low-active life course trajectories had accumulated health-compromising behaviors. Previous findings have shown that multiple health-related behaviors cluster more often in women than men (Poortinga, 2007b). The present study also generally found higher effect sizes for women. Even though several of the health-enhancing behaviors accumulated in the LTPA increasers in particular, based on the present findings (IV), it is difficult to say which was more important for the adoption of the behaviors: the increase in LTPA or the higher LTPA level achieved and maintained in adulthood among the LTPA increasers.

Out of the health-related behaviors studied here, neither sleep duration nor binge drinking were found to differ across the LTPA trajectories in middle age after adjusting the models by age, BMI, education, marital status, energy expenditure, and the corresponding earlier behaviors (IV). Thus, while LTPA seemed to be related to certain health-related behaviors, it cannot be concluded, at least based on the present findings, that PA is a gateway behavior for a healthy lifestyle that includes all the health-related behaviors of interest in this study. Identifying multiple health behavior trajectories at once could potentially further understanding of the longitudinal development and accumulation of health-related behaviors. For example, a previous study on participants aged 13 to 30 years studied the longitudinal co-development of smoking, physical exercise, fruit intake and drunkenness (Wiium et al., 2015). They identified three trajectories: 1) a conventional trajectory describing the expected age-specific norms of these behaviors, 2) a passive trajectory indicating low levels of both unhealthy and healthy behaviors, and 3) an unhealthy trajectory. Trajectory studies of this kind may offer a wider perspective on longitudinal behavioral patterns at different ages.

6.3.1 Healthier diet among persistently and increasingly actives

The clearest associations were found between dietary behavior and LTPA: participants in the persistently and increasingly active trajectories followed a healthier diet than those in less active trajectories (III, IV). Previous findings support this result by showing that PA and FVC, an indicator of a healthy diet, was accumulated by the same individuals (Fleig et al., 2015; Grant et al., 2019) and that this association between PA and a healthy diet initiated in childhood (Sallis et al., 2000). In addition, a previous longitudinal study reported that an increase, in contrast to a decrease, in PA, was associated with greater improvements in diet quality (Parsons et al., 2006). Another trajectory study, included also in the review (I), found older women with higher FVC being more likely to follow a physically active than minimally active trajectory (Nguyen et al., 2013). The fact that the present associations were stronger in women than men (IV) might be explained by previous findings indicating that women often perceive healthy eating as more important (Munt et al., 2017; Wardle et al., 2004), experience a higher need for weight control (Wardle et al., 2004), and are more health conscious (Fagerli & Wandel, 1999) than men.

While a few previous studies have suggested that PA could be a gateway behavior for healthier diet (Blakely et al., 2004; Tucker & Reicks, 2002), the present research found that the development of LTPA and FVC seemed to evolve in tandem (III). For example, the increasingly active women and men were found to increase their FVC as well whereas decreasing LTPA may be an indicator for an additional health risk, due to simultaneous detrimental changes in diet (III). Hence, it is difficult to say which of the two behaviors predicted the other, as co-development seemed to exist from childhood to middle age (III). However, since a positive significant association between overall dietary behavior and LTPA remained after adjusting for previous dietary behavior (IV), it seems likely that LTPA development predicts dietary behavior at least to some extent in middle age (IV).

Several possible explanations for the predictive effect of PA on diet have been proposed: positive experiences from PA may improve body-image (Campbell & Hausenblas, 2009), and self-esteem (Wang & Veugelers, 2008), in turn promoting individuals' self-efficacy and motivation to modify their dietary habits as well (Dutton et al., 2008; Emmons et al., 1994; Tucker & Reicks, 2002). While knowledge, skills, self-efficacy beliefs, and real or perceived barriers are thought to be important factors in health behaviors, health-related motivation is considered a primary cause of health behavior (Newsom et al., 2005). One reason why a higher PA level and following a healthier diet co-exist may be the similarity in the enablers and barriers of the two behaviors. For example, in a Finnish sample of adults aged 25-75 years, low self-efficacy and low self-control were both associated with having an unhealthier diet and being physically less active

(Borodulin, Jallinoja, et al., 2016). Enablers for both behaviors were motivation, social support and the acknowledged health benefits of each behavior (Borodulin, Jallinoja, et al., 2016).

6.3.2 Sleep difficulties less frequent in the persistently and increasingly active women

Sleep difficulties in middle age were also found to differ across the LTPA trajectories and to have medium to large effect sizes, but only in women. Among middle-aged women, sleep difficulties were more frequent among the inactive and low-active women than among their persistently and increasingly active peers (IV). This accords with previous findings showing that low PA is associated with higher risk for sleep problems and incident short sleep time in middle-aged and older people (Mesas et al., 2018). Poor sleep quality has been found to be more prevalent among women than men (Madrid-Valero et al., 2017). A recent review reported the prevalence of non-restorative sleep to vary between 19%-31% in men and 26%-42% in women (Matsumoto & Chin, 2019). Non-restorative sleep refers to the subjective experience of unrefreshing sleep (Vernon et al., 2010). In the current study, up to 20% of middle-aged women reported severe sleep difficulties versus 14% of men. Especially women have reported worry and illness to be the main reasons for their sleep problems (Armstrong & Dregan, 2014). As illness can be a barrier for PA as well (I), having an illness may be one potential explanation for the association found between lower LTPA and having sleep difficulties in women.

Comparison of the results of models 1, 2, and 3 in Study IV showed, somewhat unexpectedly, that the effect sizes of the associations between the LTPA trajectories and sleep difficulties increased when covariates were added. A factor causing this might be that the sample in model three was older than the samples in models one and two. One potential explanation for the difference between the sexes in the age group studied here is probably the female menopausal transition, which is related to adverse changes in sleep quality (Owens & Matthews, 1998; Pien et al., 2008). Thus, in addition to female sex, age may explain the associations detected between sleep difficulties and LTPA in women. Several previous studies on older adults have reported an association of higher PA with the maintenance of sleep sufficiency (Tsunoda et al., 2015), a lower probability of daytime sleepiness (McClain et al., 2014), and less frequent sleep difficulties (Mesas et al., 2018). The findings in studies examining middle-aged adults are conflicting, with some reporting an inverse (Mesas et al., 2018; Tsunoda et al., 2015) and others no association between PA and sleep quality (McClain et al., 2014). Meanwhile, a study on younger populations (adolescents) found no associations between PA trajectories and sleep time (Hanson et al., 2019).

At the same time, there is accumulating evidence to show that moderate PA has a beneficial effect on sleep quality – not only in old, but also young populations (Wang & Boros, 2021). Reduced sedentariness and increased PA and fitness could be potential prevention or treatment pathways in reducing sleep difficulties (Mochón-Benguigui et al., 2021). An updated umbrella review of the 2018 Physical

Activity Guidelines Advisory Committee report concluded that PA bouts and regular PA improve sleep outcomes (Kline et al., 2021). PA has been found to increase the time spent in deep sleep, reduce daytime sleepiness, and also decrease the time it takes to go to sleep and the time spent awake after going to sleep and before rising (Physical Activity Guidelines Advisory Committee, 2018).

6.3.3 Association of leisure-time physical activity with screen time complex

Excessive TV time (II) and higher screen time (IV) were found to coexist with both a low and, unexpectedly, also high level of LTPA in adult men, while the increasingly active men (increase observed during young adulthood after which LTPA stabilized) showed the lowest screen time (IV). A significant positive association has, however, also been found previously between higher sedentary time during leisure on a week day and very high PA in men and women (Burton et al., 2012). The present findings for women differed from those for men: the more active a woman's trajectory, the lower her TV time (II) and screen time (IV). However, the associations between screen time and LTPA disappeared and those between TV time and LTPA were attenuated after adjustments for level of education (II, IV), BMI (II, IV), smoking (II), marital status (IV) and previous screen time during leisure (IV). This indicates that the relationship between these variables, especially between LTPA and screen time in women, are explained by other factors. It was recently observed in the YFS that several factors determining changes, at least, in TV time exist, such as becoming employed, parenthood, and paying attention to health habits (Yang et al., 2018).

In comparison to women, men tend to watch more sport on television (Yang et al., 2018), engage more in video gaming (Rehbein et al., 2016) and are more sensation-seeking (Cross et al., 2013). The men in the persistently active trajectory could have included a selected group of participants seeking intense experiences via participation in sports, viewing sports and playing e-sports or other video games. If so, this might explain why higher TV time and screen time were prevalent in the persistently active men. These findings may also be explained by a previous observation that sedentary behavior and PA cannot be considered simply as functional opposites (Burton et al., 2012). It has been suggested that sedentary behavior is independent of the level of MVPA (Mansoubi et al., 2014), and that, as sedentary behavior increases, it displaces light-intensity PA (Reilly, 2016). More 24-hour time-use studies with objective PA measures are needed to better understand the complex relationship between different types of sedentary behavior and light-, moderate- and vigorous-intensity PA (Chastin et al., 2015).

6.3.4 Prevalence of smoking higher among low-actives and inactives

Smoking frequency was higher among the persistently low-active (men and women) and inactive (women) middle-aged participants when compared to their increasingly (men and women) and persistently (men) active peers. The associations of LTPA trajectories from childhood to middle age with smoking has previously also been studied in the YFS (Rovio et al., 2018; Salin et al., 2019). The findings of these two earlier studies were, as expected, supported by the present findings (IV). Rovio et al. (2018) found an association between smoking and the persistently inactive trajectory, and Salin et al. (2019) concluded that the probability of being in the highest-risk smoking categories was lower among the participants in the persistently or increasingly active trajectories.

An inverse association between LTPA and smoking has previously been reported (Swan et al., 2017), also in other PA trajectory studies (I). However, the causality between the two behaviors seems to be reciprocal. For example, among adults earlier smoking (Laaksonen et al., 2002) and nicotine dependency (Loprinzi et al., 2015) have been reported to predict lower levels of PA later on, whereas inactivity or occasional PA in adolescence have been reported to predict a higher prevalence of daily smoking in young adulthood (Kujala et al., 2007). In the YFS, those participating regularly in sport in adolescence were less likely to smoke in adulthood than those who dropped out of sport (Palomäki et al., 2018). Irrespective of the direction of causality, these two behaviors seem to be negatively associated.

The pathway model may provide an explanation for this negative association. The pathway model refers to the cumulative effects of exposures occurring during the life course which set a person on a particular pathway (Heikkinen, 2011). For example, a child who does not get social support from home or lives in an unsafe environment may get exposed to an overall disadvantaged pathway leading also to smoking and physically inactive lifestyle. Another explanation for the inverse association between the two behaviors might be due to the incongruent nature of the two behaviors (Kaczynski et al., 2008). Physical fitness and strength are usually valued among physically active individuals (Holahan et al., 2017), who might refrain from smoking when they know that smoking weakens the possibility to continue improving them. Other possible explanations for the negative association between the two behaviors include various psychological (e.g., depression), sociodemographic (e.g., ethnicity), and physiological (e.g., lung capacity) factors (Kaczynski et al., 2008).

6.3.5 No association found between binge drinking and sleep duration with leisure-time physical activity

Before adjustments, the persistently inactive women binge drank more often than those in the low-active, decreasingly, increasingly, or persistently active trajectories (Appendix 1) (IV). However, after adjustments, the association between LTPA development and binge drinking disappeared, indicating that the pre-adjustment association in women was explained by other factors. One possible explanation is that the previously reported association between several unhealthy lifestyle factors becomes stronger with increasing levels of socioeconomic deprivation (Foster et al., 2018; Ministry of Social Affairs and Health, 2013). The women identified in the inactive trajectory were more likely to be socioeconomically disadvantaged, which could explain the accumulation of the two unhealthy behaviors before adjusting for education. It is, however, interesting that the same phenomenon was not seen in men before adjustment. Compared to Finnish women, a larger proportion of Finnish men binge drink and find justification for their drinking (Mäkelä et al., 2018). Thus, drinking may be perceived as more culturally acceptable in men and as a norm for men more than it is for women. If so, this might explain why the male binge drinkers were more evenly distributed across the LTPA trajectories despite of SES.

Overall, previous findings on the associations between PA and alcohol consumption are conflicting. A longitudinal study with Finnish participants found that weekly alcohol intoxication was more common in young adulthood among those who had been persistently inactive in adolescence (Korhonen et al., 2009). At the same time, the regular and occasional consumers of alcohol in the YFS data were not, as might be expected, in the inactive, but in the persistently active trajectory in middle age (Rovio et al., 2018). Two other reviewed trajectory studies (I), in addition to that of Rovio et al. (2018), reported similar results (Aggio et al., 2018b; Nguyen et al., 2013). A positive association of vigorous PA with alcohol use has also been found in US college students (Graupensperger et al., 2018) and, more generally, in the US population under age 50 (Lisha et al., 2011).

Sleeping the recommended 7-9 hours a night (Hirshkowitz et al., 2015) did not differ across the LTPA trajectories in either sex. This contradicted earlier longitudinal findings among middle-aged and older adults that a higher baseline level of PA predicted lower risk for incident short sleep duration (Mesas et al., 2018). This difference in findings might be due to inaccuracy in the measure of sleep duration used in the present study (IV), which was self-reported, compared to the gold-standard laboratory polysomnography used by Mesas and his colleagues (2018). Diverse electronic devices, which are more accessible and easier to use than polysomnography, are being developed to provide more accurate measures of sleep than survey data. Multi-sensor devices have proved to outperform motion-only devices in measuring sleep, although further developments are needed to improve accuracy, especially in sleep stage classification and wake detection (Menghini et al., 2021).

6.4 Topicality of physical activity trajectory studies

The use of trajectory modeling in studying the development of PA seems to have become increasingly popular since 2010. Of the 27 articles included in the systematic review (I), 24 were published from 2010 onward. The rate of production of PA trajectory studies has since increased. At least 13 articles (Aggio et al., 2018a, 2019, 2020; Howie et al., 2020; Inada et al., 2021; Laddu et al., 2020, 2018; Oh et al., 2021; Pate et al., 2019; Pettee Gabriel et al., 2019; Saint-Maurice et al., 2019; Sanchez-Sanchez et al., 2020; Sandhu et al., 2020) have been published since the systematic search performed for the present review (I) in February 2018. This fast-growing number of publications testifies to the increased interest in the use of trajectory modeling to better understand the complex development of PA during the life course and the factors relating to or explaining trajectory class membership.

Like the original 27 publications included in the systematic review (I), the most recent PA trajectory studies have all been conducted in high-income countries. Older adults were highly represented in these recent trajectory studies (Aggio et al., 2018a, 2019, 2020; Inada et al., 2021; Laddu et al., 2020, 2018; Pettee Gabriel et al., 2019; Sanchez-Sanchez et al., 2020; Sandhu et al., 2020). In one study, however, LTPA trajectories from adolescence to adulthood were identified, although retrospectively (Saint-Maurice et al., 2019). In three other studies children, adolescents or young adults were studied (Howie et al., 2020; Oh et al., 2021; Pate et al., 2019). PA trajectory studies on preschool aged children continue to be lacking. Three of the recent studies assessed PA with objective measures (Inada et al., 2021; Oh et al., 2021; Pate et al., 2019) while the rest used self-reported data. Thus, there has not been any marked increase in PA trajectory studies using objective measures of PA. In the future, as suitable longitudinal data become available, PA trajectory studies should also be conducted in low- and middle-income countries, use objective measures of PA, and also study preschool children.

Previously, unhealthy behaviors have been found to be more prevalent among men, lower social class households, singles, and economically inactive people (Poortinga, 2007b). The studies included in the review supported this observation by showing that the attributes of male sex, being single, being Caucasian, being a non-smoker, having higher SES, having no chronic illnesses, having normal body weight, and having family support for PA were more likely to characterize participants with either persistent or increasing PA when compared to less active or decreasingly active individuals (I). However, the factors selected for study in relation to the PA trajectory membership in the most recent studies, as in those reviewed here (I), differed widely. Biological, psychological, environmental, social, cultural and behavioral factors have all previously been studied as correlates and determinants of PA (Aleksovska et al., 2019; Bauman et al., 2012; Sallis et al., 2016; Sterdt et al., 2014). These factors should all be explored in greater depth at different ages and in different populations in PA trajectory studies, as this may help target PA promotion to key groups. This is important, as it is still largely unknown which determinants are the most important at each life stage, not to mention whether, and if so, at what points these determinants change (Corder et al., 2009).

6.5 Methodological considerations

6.5.1 Strengths

The relatively large YFS dataset (II-IV) comprising six age cohorts and several measurement points during a follow-up of over 30 years adds to the value of this dissertation research. Moreover, the participants were recruited from all over Finland, and hence form a study sample representative of the general Finnish population. The data enabled the identification of life course LTPA trajectories all the way from childhood into middle age and investigation of their associations with several other health-related behaviors (dietary behavior, screen time, TV time, smoking, binge drinking, and sleeping behavior). Several covariates were considered and included in the statistical analyses.

This dissertation included the first systematic review (I) of studies using a rather novel methodological approach (finite mixture modeling / trajectory modeling) to the study of PA behavior. Trajectory modeling enabled thorough exploitation of the longitudinal nature of the data to be studied (not only general PA trends and mean values), and close examination of the variation in the magnitude, rate, and timing of possible change in PA. As the LTPA trajectories were modeled via latent profile analysis (II–IV), uncertainty in class membership was taken into account. Furthermore, trajectory modeling is a data-driven method, meaning that it is principally based on objective model fit indicators in identifying the optimal number of latent trajectory classes (Twisk & Hoekstra, 2012).

6.5.2 Limitations

One limitation of this dissertation is the use of self-reports (II-IV). Self-reported (i.e., subjective) data is often imprecise, and can thus lead to biased estimates of associations toward the null, meaning that the strength of the true associations is underestimated (Corder et al., 2009). Subjective reporting is also prone to recall bias (Durante & Ainsworth, 1996), and may lead to under- and over-reporting (Downs et al., 2014; Girschik et al., 2012; Männistö et al., 1996; Prince et al., 2020). Under- and over-reporting may result from, for example, a tendency to report what is socially desirable (Adams et al., 2005), especially among members of specific participant groups, e.g., participants who are overweight or obese (Paalanen et al., 2006). However, the purpose of this study was not to precisely quantify the studied behaviors per se, but to group and classify the participants in relation to the study population.

Misinterpretation of questions or different interpretation of the same questions over time may induce biased results. For example, awareness of the importance of PA for health increased in Finland during the study period (Vuori et al., 2004). The participants might have had a different perspective on LTPA in 1980 than at the beginning of the 21st century. Moreover, the questionnaire included items that used the Finnish term "liikunta" which does not translate easily into English. LTPA is an approximate, but not perfect, translation of it. "Liikunta" refers to human organized and un-organized PA in general, not only to sports (Laakso et al., 2008). It is understood to refer to intentional and voluntary PA, and thus often excludes occupational PA. However, while the participants' occupational and transport activity were not separately assessed and included in the LTPA index, some participants might define, for example, their active mode of transport as part of their "liikunta" (i.e., LTPA).

It can be argued that the variables included in the LTPA index were not unambiguous, as the index also included aspects of LTPA other than intensity, duration and frequency (Pettee Gabriel et al., 2012). The original aim of the LTPA index (Telama et al., 2005) was not to only obtain information on PA levels in the absence of objective measures in large epidemiological cohort studies, but also to assess the type and context of the LTPA phenomenon. The LTPA index comprised multiple variables, as it would have been difficult to capture LTPA behavior with just one variable. This was done to avoid item-specific measurement error (Boateng et al., 2018). Despite these limitations, the LTPA index has been validated against data collected with accelerometers and pedometers (Hirvensalo et al., 2017; Mansikkaniemi et al., 2012; Pälve, 2017, pp. 30-35) and the results indicated that the questionnaire was acceptably valid as a tool for subjectively assessing LTPA.

Other YFS variables also had their limitations (II-IV). While the definition of TV time (II) was broadened to screen time during leisure (IV), the measure of screen time did not include the use of electronic mobile devices such as smart phones or tablet computers. Furthermore, the wording of the study question on binge drinking used with both sexes was identical (IV). Had the question been phrased differently for women and men, a lower threshold value could have been used for women, potentially leading to a larger proportion of women being identified as binge drinkers. The variable of sleep duration, which was based on recommended levels, did not seem to be precise enough to differentiate between participants. Overall sleep duration in hours was also tested across the LTPA trajectories, but no associations were detected. More accurate, objective measures of sleep duration might have shown different results. The models in Study IV were adjusted for previous corresponding behavior in order to ascertain whether the association between LTPA and a behavior was predicted by LTPA or by the behavior itself. This led to a lower sample size, and potential selection bias, in the fully adjusted models. Hence sensitivity analyses were performed. Sleeping behavior in 1986 was only assessed in the three oldest age cohorts (IV), which meant an older sample when compared to the samples of the other fully adjusted models. This should be considered when analyzing the results between the LTPA trajectories and sleeping difficulties.

Conclusions on causality between the LTPA trajectories and other health-related behaviors in observational studies are susceptible to bias, such as reverse causation. Although several covariates were used, the associations between the studied behaviors may be affected by unmeasured confounders (e.g., chronic diseases (Marques et al., 2018; Vancampfort et al., 2017), mental health issues (Abu-Omar et al., 2004), temperament (Karvonen et al., 2020), transitions and life events (Hirvensalo & Lintunen, 2011), social support, cultural norms and practices, social, built and natural environment, urbanisation (Bauman et al., 2012), or occupational status (Hirvensalo & Lintunen, 2011)). The study sample also represented a Finnish population (II-IV), and therefore the results are not generalizable to other populations with, for example, a different socio-economic or ethnic background. In addition, the amount of missing data was rather high, as many participants dropped out from the YFS in the successive follow-ups. Interestingly, some also returned in the study later on (Raitakari et al., 2008). Missing data were assumed to be missing at random, a choice which might add to the reliability of the trajectories identified. It has been demonstrated that even, for example, failing to take into account a cause of missingness often only has a minor impact on estimates and standard errors (Collins et al., 2001).

When comparing the PA trajectories of the different studies included in the systematic review (I), the use of self-reported PA data once again presented challenges. As in the YFS, the reviewed studies using self-reported data aimed at classifying the participants in relation to each other according to their PA level rather than measuring the absolute amount of PA. This led to a situation where, for example, the label "highly active trajectory" given to a trajectory class identified in a study sample of older people might possibly have been labelled "active" in a different study with a sample of younger people. In the future, the increasing use of objective PA measures will improve comparability between different study populations. Comparing the findings of the reviewed studies (I) was also challenging due to heterogeneity in the study populations, sample sizes, follow-up duration, measurement times, time between measurements, participant age, the names researchers gave to their trajectories, the measures used (PA, exercise, and sport participation), exposure and outcome variables, the organization of data in trajectory modeling (i.e., age vs. measurement year), and the finite mixture models used. For example, if SES in a given study population was lower than in other study populations, the former could be expected to contain a larger group of inactive individuals, whereas if male sex was over-presented, then the prevalence of physically active individuals might be higher.

Finally, researchers need to acknowledge that trajectory modeling has its limitations. First, membership of a trajectory is not certain (Warren et al., 2017) but only probable. Moreover, the number of trajectory classes is not immutable (Nagin & Tremblay, 2005): while the choice of the optimal number of classes is based on various formal criteria, informal criteria are also used (Warren et al., 2017) which may lead to selection bias. These can include the proportion of cases assigned to the smallest trajectory class, interpretability, and model convergence (Jung & Wickrama, 2008; Warren et al., 2017). Length of follow-up and time between measurement points have also been found to affect the number of trajectories identified (Van de Schoot et al., 2017). For example, a long interval between measurement points might lead to situation where certain PA patterns are not detected.

The choice of the statistical approach to be used in identifying trajectories may itself have an effect on the results (Warren et al., 2017). This has also been observed in the YFS. When latent profile analyses (Salin et al., 2019) (II-IV) or group-based trajectory modeling (Rovio et al., 2018) were used, the identified trajectories accorded rather well with each other. However, in the YFS, the first study using trajectory modeling for participants aged 9-49 years identified slightly differing, rather stable PA trajectories (highly, moderately and lightly active) (Kaseva et al., 2016). The researchers used latent class growth analyses and only tested linear and quadratic terms. Had they continued the analyses to include cubic terms, this would have shown whether the trajectories were more in line with those identified in the YFS later on (III, IV) (Rovio et al., 2018; Salin et al., 2019). Another explanation for this difference might be that Kaseva et al. (2016)

used AIC despite the current recommendation that the BIC and ABIC are the best model fit measures for determining the final number of classes compared, for example, to the AIC or Lo-Mendel-Rubin-likelihood ratio test (Van de Schoot et al., 2017). Fortunately, scientific knowledge gradually accumulates. Statistical collaboration and the understanding of trajectory modeling have evolved during recent years within the YFS research team, although work in these areas is still needed.

7 CONCLUSIONS AND SUGGESTIONS FOR FUTURE DIRECTIONS

In this dissertation, the diverse development of PA between and within individuals during the life course and the role of LTPA development in the adoption of a healthy lifestyle were studied. The main conclusions, implications, and suggestions for future studies are presented below.

1. The identification of diverse PA trajectory classes may be important in building epidemiological evidence database that can aid policy decision-making in such areas as identifying the key target groups for PA interventions and seeking to improve public health. The findings of this research further supported the observation that the declining trend in PA is often initiated already in childhood, not, as previously thought, in adolescence, and that the prevalence of inactivity is high and increases with age (I, III, IV). The multiple declining PA trajectories identified in childhood and adolescence (I) indicated that the participants who further decreased their already low level of PA were at higher risk of becoming inactive later on than those whose PA decreased from high to moderate. At the same time, among younger and older adults, the few increasingly active trajectories identified indicated that to be physically active in adulthood does not necessarily require the initiation of a physically active lifestyle already in childhood (I, III, IV). Thus, while it would be important to target PA interventions to children before their PA levels decline, PA interventions with various actions at multiple levels and aimed at all age groups according to the needs of specific key groups are warranted. In addition, no studies thus far have sought to identify multiple PA trajectories among preschool-aged children. It would be important to learn whether a trajectory of preschool-aged children who are at higher risk of becoming inactive (i.e., identified as showing declining trend in PA) than those in other trajectories exists at that early age. The use of objective PA measures should also be increased in order to identify trajectories of sedentary behavior, and of light-, moderate- and vigorous-intensity PA

and compare their associations to health outcomes. As only one previous PA trajectory study has examined types of PA separately (Aggio et al., 2019), this aspect merits further study. The types and domains of PA could be studied within different PA trajectories to find out whether the domain of PA (leisure-time, occupational / school-based, transportation, household) matters in relation to health outcomes.

2. LTPA was associated with certain health-enhancing behaviors, but did not, however, appear to be a gateway behavior for adopting all the studied behaviors (II-IV). The findings showed that following a healthier diet, smoking less, experiencing less sleep difficulties (women only) and having lower screen time (increasingly active men only) was more probable among the participants identified in the persistently or increasingly active trajectories from childhood to middle age, while the unhealthy side of these behaviors accumulated in those identified in the persistently inactive or low-active trajectories (III, IV). This is a concern from the public health standpoint, as the largest proportion of participants, of both sexes, were in the low-active trajectories. Putting effort into adopting or maintaining a physically active lifestyle, starting from early childhood, could be important for adopting healthy lifestyle later in life. To achieve favorable changes in these behaviors, cross-government and multisector approaches are needed that facilitate the integration of PA, non-smoking and a healthy diet in multiple daily settings. Causality should also be addressed in future intervention studies, preferably with objective measurements of PA. In addition, more longitudinal studies investigating the joint development of different health-related behaviors are needed. Furthermore, research is needed to find out whether the positive associations between LTPA and specific health-related behaviors are explained by other factors, such as higher health consciousness or social factors. It is essential to understand how lifelong healthy behaviors can be created and sustained in those who have the most to gain from adopting them.

3. PA behavior may change during the life course for diverse reasons. The factors related to PA trajectory membership at different ages have not yet been systematically and thoroughly studied (I). Moreover, all the PA trajectory studies have been conducted in high-income countries. More PA trajectory studies are needed from low- and middle-income countries to better understand the differences in PA development, and especially the potentially different determinants of trajectory memberships, between these countries. As trajectory modeling enables study of those whose PA behavior changes over time, future studies should investigate the factors explaining why certain people managed to increase their PA level. This could help to find means to assist physically inactive individuals to become more active.

4. Trajectory modeling was found to be a methodological tool that helps in visualizing the diverse development of PA behavior and provides information on the heterogeneity and complexity of PA behavior at different ages. However, researchers need to be aware of the uncertainties related to trajectory modeling. No consensus has yet been achieved on the optimal statistical approaches for identifying developmental trajectories (I). Specification of the most suitable statistical model for identifying PA trajectories would help in collectively amassing knowledge in this field in the future.

YHTEENVETO (SUMMARY IN FINNISH)

LIIKUNTA-AKTIIVISUUS ELÄMÄNKULUSSA JA SIIHEN YHTEYDESSÄ OLEVAT ELINTAVAT: LASTEN SEPELVALTIMOTAUDIN RISKITEKIJÄT -TUTKIMUS

Johdanto

Liikunnan hyödyt terveydelle, toimintakyvylle ja hyvinvoinnille ovat yleisesti tunnustettuja (Physical Activity Guidelines Advisory Committee, 2008, 2018). Tästä huolimatta 81 % lapsista ja 28 % aikuisista ei saavuta terveyttä edistäviä liikuntasuosituksia (Bull ym. 2020; Guthold ym. 2020). Samanaikaisesti ei-tarttuvat taudit, kuten sydän- ja verisuonisairaudet, tyypin II diabetes ja tietyt syövät, aiheuttavat peräti 73 % kuolemista maailmanlaajuisesti (Roth ym. 2018). Epäterveellisiä elintapoja ovat mm. vähäinen liikunta-aktiivisuus, epäterveellinen ravinto, epäsäännöllinen ja liian lyhyt yöuni, liiallinen istuminen, tupakointi ja liiallinen alkoholinkäyttö. Ne lisäävät riskiä sairastua ei-tarttuviin tauteihin (Jike ym. 2018; Liu ym. 2017; Naghavi ym. 2017; Noble ym. 2015; Young ym. 2016). Aikaisempien poikittaistutkimusten mukaan terveelliset elintavat kasautuvat usein samoille henkilöille, kun puolestaan epäterveelliset kasautuvat toisille (Noble ym. 2015). Jälkimmäinen on erityisen vahingollista terveydelle (Berrigan ym. 2003; Ding ym. 2015; Poortinga, 2007b), kun puolestaan kokonaisvaltaisen terveellisen elämäntyylin omaksuminen olisi hyvinvoinnin kannalta tärkeää.

Liikunnan on ehdotettu olevan reitti muiden terveellisten elintapojen omaksumiseen (Blakely ym. 2004; Fleig ym. 2015; Kline ym. 2021; Pronk ym. 2004; Tucker & Reicks, 2002). Aiemmat tutkimukset ovat tyypillisesti keskittyneet liikunta-aktiivisuuden ja jonkin yksittäisen terveyskäyttäytymisen yhteyden tutkimiseen. Toistaiseksi tutkimuksissa on käytetty rajallisesti usean mittauspisteen pitkittäisaineistoja selvittämään liikunta-aktiivisuuden yhteyttä muihin elintapoihin. Yksilöiden vapaa-ajan liikunta-aktiivisuuden pysyvyyttä tai sen muutoksia elämänkulun aikana tunnetaan toistaiseksi huonosti. Viimeisen kymmenen vuoden aikana pitkittäistutkimuksissa on kuitenkin alettu hyödyntämään henkilökeskeistä kehityspolkuanalyysiä eli trajektorimallinnusta, joka mahdollistaa liikunnan määrän, pysyvyyden ja ajoittumisen vaihtelun tutkimisen. Kehityspolku eli trajektori kuvastaa yksilön käyttäytymisen kehittymistä pitkän ajan kuluessa (Nagin, 2005; Muthén & Muthén, 2017). Analyysi jakaa tutkimushenkilöt alaryhmiin kehityspolkujen muotojen perusteella siten, että kehityspolut ovat ryhmän sisällä mahdollisimman samanlaisia, mutta eroavat eri alaryhmien välillä. Toisin sanoen analyysiä käytetään, kun isosta populaatiosta halutaan tunnistaa käyttäytymiseltään samankaltaisia alaryhmiä (Nagin 2005). Analyysin vahvuus on se, että tutkija ei itse määritä raja-arvoja alaryhmille, jolloin myös ennalta odottamattomat ryhmät voidaan identifioida (Nagin & Tremblay, 2005; Twisk, 2014; Twisk & Hoekstra, 2012; Warren ym. 2017).

Tämän väitöstutkimuksen tavoitteena oli ymmärtää liikunta-aktiivisuuden kehittymistä – sen pysyvyyttä ja muuttumista – elämänkulun aikana ja tutkia, miten erilaiset liikunta-aktiivisuuden kehityspolut ovat yhteydessä muuhun terveyskäyttäytymiseen. Ensin tutkimusaluetta kartoitettiin systemaattisella kirjallisuuskatsauksella. Tämän jälkeen Lasten Sepelvaltimotaudin Riskitekijät -pitkittäisaineistosta identifioitiin vapaa-ajan liikunta-aktiivisuuden alaryhmät naisille ja miehille lapsuudesta aikuisuuteen kehityspolkuanalyysilla. Seuraavaksi tutkittiin näiden alaryhmien yhteyttä muihin elintapoihin: ravitsemukseen, ruutuaikaan, uneen, tupakointiin ja alkoholinkäyttöön. Pyrkimyksenä oli selvittää, minkälaisia yhteyksiä eri liikuntaryhmien ja elintapojen väliltä löytyy ja kasautuvatko terveelliset tai epäterveelliset elintavat tietyille liikuntaryhmille. Mikäli liikunta-aktiivisuuden lisääminen on yhteydessä suotuisaan muutokseen muissakin elintavoissa, voisi väestön liikunta-aktiivisuuden edistäminen johtaa laajempaan positiiviseen muutokseen elintavoissa, mistä olisi merkittävää kansanterveydellistä hyötyä.

Tutkimuskysymykset

Tutkimuskysymykset neljälle osatutkimukselle (I-IV) olivat:

1. Miten väestön liikunta-aktiivisuus kehittyy elämänkulun aikana lapsuudesta vanhuuteen ja mitkä tekijät ovat yhteydessä liikunta-aktiivisuuden erilaiseen kehittymiseen aikaisempien kehityspolkututkimusten mukaan (I)?

2. Miten erilaiset vapaa-ajan liikunta-aktiivisuuden alaryhmät ovat yhteydessä television katselun alaryhmiin suomalaisilla aikuisilla (II)?

3. Miten erilaiset vapaa-ajan liikunta-aktiivisuuden alaryhmät ovat yhteydessä kasvisten ja hedelmien käyttöön lapsuudesta keski-ikään suomalaisilla naisilla ja miehillä (III)?

4. Eroavatko elintavat (ravintotottumukset, vapaa-ajan ruutuaika, unen laatu ja määrä, tupakointi ja humalahakuinen juominen) liikunta-aktiivisuuden eri alaryhmien välillä keski-ikäisillä suomalaisilla naisilla ja miehillä (IV)?

Aineisto, muuttujat ja mittausmenetelmät

Väitöskirjatutkimus koostui osatutkimuksista I-IV. Systemaattinen kirjallisuuskatsaus (I) kokosi yhteen kehityspolkuanalyysillä liikunta-aktiivisuutta väestön elämänkaaren aikana tutkineet kansainväliset vertaisarvioidut pitkittäistutkimukset. Systemaattiset haut tehtiin tietokannoista PubMed (Medline), Web of Science, ja CINAHL aikarajauksella 1.1.2000–13.2.2018. Katsauksen luotettavuuden lisäämiseksi kaksi artikkelin kirjoittajaa arvioi itsenäisesti hakutulokset sekä mukaan otettujen artikkeleiden tutkimusmenetelmien laadun.

Osatutkimuksissa II-IV käytettiin yli 30 vuotta kestäneen Lasten sepelvaltimotaudin riskitekijät (LASERI) -pitkittäistutkimuksen aineistoa, joka mahdollisti elintapojen tutkimisen aina lapsuudesta keski-ikään. LASERI-tutkimuksessa on mukana viisi yliopistokaupunkia (Helsinki, Kuopio, Oulu, Tampere ja Turku) ja niiden lähiseutu. Tutkimuksen alkuperäinen otos valittiin kansallisesta väestörekisteristä satunnaistamalla ja se koostui 1764 pojasta ja 1832 tytöstä (83 % kutsutuista). Mukana on kuusi ikäkohorttia, jotka ovat syntyneet vuosina 1962–1977. Heitä on tutkittu yhteensä kahdeksan kertaa vuosina 1980, 1983, 1986, 1989, 1992, 2001, 2007 ja 2011–12 (Raitakari ym. 2008; Åkerblom ym. 1985, 1991). Tässä väitöskirjatutkimuksessa tutkittavat olivat 9-18-vuotiaita vuonna 1980 ja 33-49-vuotiaita vuosien 2011-12 aineistonkeruussa (n=2060, 55 % naisia). Osatutkimuksessa II tutkittiin 24-49-vuotiaita aikuisia (n=2934, 54 % naisia). Osatutkimuksissa III ja IV tutkittiin liikunta-aktiivisuuden kehittymistä aina lapsuudesta keski-ikään otoskoon ollessa 3536 (51 % naisia) osatutkimuksessa III ja 3553 (51 % naisia) osatutkimuksessa IV.

Itseraportoitujen kyselylomakkeiden avulla kerättiin tiedot vapaa-ajan liikunta-aktiivisuudesta sekä muista elintavoista (II-IV). Liikunta-aktiivisuutta on tutkittu kaikkina mittausvuosina usealla eri kysymyksellä koskien mm. liikunnan intensiteettiä, frekvenssiä ja määrää. Näistä on koostettu liikunta-aktiivisuutta kuvaava indeksi (Rovio ym. 2018; Telama ym. 2005, 2006), joka on validoitu suhteessa objektiivisiin mittausmenetelmiin (Hirvensalo ym. 2017; Mansikkaniemi ym. 2012; Pälve, 2017, s. 30–35; Telama ym. 2005) (II-IV). Ennen vuotta 2007 kasvisten ja hedelmien syöntitiheyttä, edeltävien 6–12 kuukauden aikana, kysyttiin kuusiportaisella asteikolla (III). Vuonna 2007 otettiin käyttöön kattavampi ravintokysely, jossa itsearvioidut annoskoot muutettiin grammoiksi Finelin (elintarvikkeiden kansallinen koostumustietopankki) avulla (III, IV). Terveellistä ravintoa kuvaava indeksi luotiin osatutkimukseen IV vuosien 2011–12 kerätyn aineiston pohjalta. Terveellistä ravintoa kuvasivat täysjyvätuotteiden, hedelmien, kasvisten, vihannesten, kalan, ja ruokaöljyn monipuolinen ja runsas käyttö. Epäterveellistä ravintoa puolestaan kuvasivat punaisen lihan, sokeroitujen virvoitusjuomien, paistettujen perunoiden ja jälkiruokien runsas nauttiminen. Keskimääräinen päivittäinen vapaa-ajan televisio- ja kokonaisruutuaika itseraportoitiin (II, IV). Univaikeuksia arvioitiin validoidulla neliportaisella Jenkinsin asteikolla (Crawford ym. 2010; Jenkins ym. 1988) (IV). Tutkittavilta kysyttiin keskimääräistä yöunen kestoa, minkä perusteella muodostettiin dikotominen muuttuja perustuen suositukseen nukkua 7–9 tuntia yössä (Hirshkowitz ym. 2015) (IV). Itseilmoitettu tupakointi jaoteltiin neljään ryhmään: tupakoimaton, tupakoinnin lopettanut, satunnaisesti tupakoiva ja säännöllisesti tupakoiva (IV). Humalahakuista juomista (yli kuusi annosta kerralla) kysyttiin sen useuden mukaan ja käsiteltiin neliluokkaisena. Kovariaatteina malleissa käytettiin painoindeksiä, koulutustaustaa, siviilisäätyä, energiansaantia ja aikaisempia vastaavia elintapoja.

Latenttien profiilien analyysiä käytettiin vapaa-ajan liikunta-aktiivisuuden alaryhmien (ts. kehityspolkujen / trajektoreiden) identifiointiin (II-IV). Eri liikunta-aktiivisuuden alaryhmien yhteyttä muihin elintapoihin tutkittiin laskemalla transitioiden todennäköisyyttä (II) tai käyttämällä Bolck-Croon-Hagenaars-menetelmää (III, IV).

Tulokset

Tutkimus osoitti, että liikunta-aktiivisuudessa tapahtuu muutoksia elämänkulun aikana. Tutkimuksessa identifioitiin liikunta-aktiivisuuden alaryhmiä, jotka poikkesivat toisistaan sen suhteen, miten liikunta-aktiivisuus kehittyy eri ikävaiheissa (I-IV). Systemaattiseen kirjallisuuskatsaukseen valikoitui 27 artikkelia (I). Katsauksen mukaan suhteellisesti suurin osa väestöstä identifioitui vähän liikkuvien tai inaktiivisten ryhmiin trendin vahvistuessa ikääntymisen myötä. Liikunta-aktiivisuuden väheneminen näyttää alkavan usein jo kouluiässä ja liikunta-aktiivisuuden taso vaihtelee eniten lapsuudessa ja nuoruudessa sen vakiintuessa yleensä aikuisuudessa (I). Liikunta-aktiivisuuden lisääjien ryhmiä kuitenkin havaittiin aikuisilla ja ikääntyvillä, mutta ei juurikaan lapsilla ja nuorilla (I). Vähäinen liikkuminen vaikutti olevan muuttumattomampaa kuin liikunta-aktiivisuus elämänkulun aikana (I, III, IV).

Suomalaisväestöstä lapsuudesta (9-vuotiaasta) keski-ikään (49-vuotiaisiin) identifioidut vapaa-ajan liikunta-aktiivisuuden alaryhmät (III, IV) olivat pääosin samantyyppisiä kuin aikaisemmissa tutkimuksissa (I). Niin naiset kuin miehet jakautuivat seuraaviin alaryhmiin: aktiivisesti liikkuviin, liikunnan lisääjiin, liikunnan vähentäjiin ja vähän liikkuviin. Lisäksi naisilla identifioitui erillinen liikunnallisesti inaktiivinen ryhmä (III, IV). Suurin alaryhmä niin naisilla (53 %) kuin miehillä (41 %) oli lapsuudesta keski-ikään vähän liikkuvien ryhmä, kun puolestaan pienin alaryhmä niin naisilla (3 %) kuin miehillä (12 %) oli aktiiviliikkujien ryhmä. Muutosryhmistä etenkin naisten liikunnan lisääjien ryhmässä (15 %) oli havaittavissa selkeä nouseva kehityssuunta aina 12-vuotiaasta keski-ikään saakka ja miesten liikunnan vähentäjien ryhmässä (16 %) havaittiin selkeä laskeva kehityssuunta.

Tulokset osoittivat vapaa-ajan liikunta-aktiivisuuden ja ravintotottumusten olevan vahvasti yhteydessä toisiinsa: aktiivisesti liikkuvat ja liikuntaa lisänneet söivät terveellisemmin kuin vähän liikkuvat tai liikunnallisesti inaktiiviset (III, IV). Myös tupakoimattomuus oli yleisempää aktiiviliikkujilla (miehillä) ja liikunnan lisääjillä (miehillä ja naisilla) verrattuna vähemmän liikkuviin. Television katselu oli yleisempää vähän kuin aktiivisesti liikkuvilla naisilla (II), joskaan vakioinnin jälkeen yhteyttä ei havaittu tutkittaessa kokonaisruutuaikaa vapaa-ajalla (IV). Liikunta-aktiivisuuttaan nuoruudessa lisänneet miehet olivat vähemmän ruudun äärellä vapaa-aikanaan kuin vähän liikkuvat (IV). Toisaalta aktiivisesti läpi elämänsä liikkuneilla miehillä oli keskimäärin enemmän ruutuaikaa kuin liikunta-aktiivisuuttaan nuoruudessa lisänneillä miehillä (IV). Vähän liikkuvilla ja inaktiivisilla naisilla oli useammin univaikeuksia kuin liikuntaansa lisänneillä tai aktiivisesti liikkuneilla naisilla keski-iässä (IV). Havaitut yhteydet vapaa-ajan liikunta-aktiivisuuden alaryhmien ja tutkittujen elintapojen välillä olivat usein naisilla vahvempia kuin miehillä (IV). Unen pituus ja humalahakuinen juominen eivät näyttäneet eroavan naisilla tai miehillä vapaa-ajan liikunta-aktiivisuuden alaryhmien välillä tilastollisesti merkitsevästi (IV).

Tutkimuksen vahvuudet ja rajoitteet

Tutkimuksen vahvuutena on sen suhteellisen laaja, kuusi ikäkohorttia ja kahdeksan mittauspistettä sisältävä, suomalaisväestöä hyvin edustava tutkimusaineisto, jota on kerätty samoilta henkilöiltä yli 30 vuoden ajan (II-IV). Lisäksi osana tätä väitöskirjatutkimusta laadittiin ensimmäisen kerran systemaattinen kirjallisuuskatsaus (I), joka kokosi yhteen liikunta-aktiivisuutta kehityspolkuanalyysillä *(finite mixture modeling*) tutkineet pitkittäistutkimukset**.**

Rajoitteina voidaan pitää itseraportoituun tietoon perustuvia tuloksia, joihin voi liittyä harhaa. Tämä johtuu esimerkiksi tutkittavien virhetulkinnoista, muistista (Durante & Ainsworth, 1996) ja sosiaalisesti hyväksyttyjen vastausten antamisesta (Adams et al., 2005), jotka johtavat tulosten yli- tai aliarvioimiseen (Downs ym. 2014; Girschik ym. 2012; Männistö ym. 1996; Prince ym., 2020). Aineistokatoa ilmenee mittausvuosien välillä. Pitkittäistutkimuksissa kausaalisuuden varmistaminen on haastavaa, koska käänteinen kausaalisuus on mahdollista. Tässä tutkimuksessa (IV) aikuisuuden elintavat vakioitiin vastaavalla elintavalla lapsuudesta tai nuoruudesta, jotta voitaisiin poissulkea kyseisen elintavan merkitys liikunta-aktiivisuuden ja elintavan yhteyden väliltä. Tästä huolimatta muut tutkimattomat tekijät voivat sekoittaa kausaalista yhteyttä. Systemaattiseen kirjallisuuskatsaukseen (I) koottujen tulosten vertaamista vaikeuttivat erot tutkimusasetelmissa ja -menetelmissä (esim. otoskoissa ja -rakenteissa, seurantaajoissa, mittauspisteiden erimittaisissa väleissä, samankaltaisten liikunta-aktiivisuuden alaryhmien erilaisessa nimeämisessä, liikunta-aktiivisuuden erilaisessa mittauksessa ja erilaisissa tilastollisissa menetelmissä).

Johtopäätökset

Tutkimus tarkensi aikaisempaa tutkimustietoa vapaa-ajan liikunta-aktiivisuuden pysyvyydestä ja muutoksista väestötasolla. Tutkimus myös vahvisti aikaisempaa tutkimustietoa (Telama, 2009), jonka mukaan liikunnallisesti inaktiivinen elämäntyyli on pysyvämpää kuin liikunnallisesti aktiivinen. Suurin osa tutkittavista identifioitiin vähän liikkuvien tai inaktiivisten ryhmiin (I, III, IV) liikunta-aktiivisuuden vähenemisen alkaessa usein jo kouluiässä (I) ja vähän liikkuvien osuuden kasvaessa iän myötä (I). Tämän vuoksi on tärkeä etsiä keinoja, miten pysyväksi kehittyvää liikunnallista inaktiivisuutta voidaan yhteiskunnallisesti estää lapsuudesta alkaen. Kehityspolkuanalyysillä identifioidut erilaiset liikunta-aktiivisuuden alaryhmät havainnollistavat myös sitä variaatiota, joka kuvattaessa väestön keskimääräistä liikunta-aktiivisuutta jää tavoittamatta. Aikuisilla havaittiin esimerkiksi liikunta-aktiivisuuden lisääjien ryhmiä (I, III, IV). Tämä osoitti, että liikunnallisesti aktiivinen elämäntyyli aikuisuudessa ei aina vaadi liikunnallisesti aktiivista lapsuutta. Jatkossa liikuntaa lisänneiden kehityspolkujen taustalla olevia syitä ja motiiveja olisi tärkeä ymmärtää, jotta liikunnan edistämisen toimenpiteitä voidaan kohdentaa tarkoituksenmukaisesti vähän liikkuville ja liikunnallisesti inaktiivisille väestöryhmille oikea-aikaisesti.

Tulokset osoittivat, että liikunnallisen elämäntyylin omaksuneet söivät terveellisemmin, tupakoivat harvemmin ja kärsivät harvemmin univaikeuksista (vain naiset) kuin liikunnallisesti passiivisen elämäntyylin omaksuneet. Nämä tavat ryvästyivät selkeämmin naisilla kuin miehillä, mikä saattaa liittyä naisten korostuneempaan terveystietoisuuteen sekä yleisempään haluun välttää lihomista miehiin verrattuna (Fagerli & Wandel, 1999; Munt ym. 2017; Wardle ym. 2004). Näyttää siltä, että läpi elämän jatkuva liikunta-aktiivisuus tai sen onnistunut lisääminen on tärkeää, paitsi sen suorien terveyshyötyjen, myös yllä mainittujen terveellisten elintapojen omaksumisen vuoksi. Toisaalta tulokset eivät kaikilta osin tukeneet sitä, että liikunta-aktiivisuus olisi reitti kokonaisvaltaiseen terveelliseen elämäntyyliin jokaisen tutkitun elintavan osalta. Vapaa-ajan liikunta-aktiivisuuden ja ruutuajan yhteys oli kompleksinen, mikä saattaa liittyä mahdolliseen runsaaseen paikallaoloon liikunnallisesti aktiivisesta elämäntyylistä huolimatta. Jatkossa liikunta-aktiivisuuden eri alaryhmien kausaalista yhteyttä muihin elintapoihin tulisi tutkia tarkemmin interventioissa huomioiden useampia taustatekijöitä ja käyttäen objektiivisia mittareita mm. istumiseen käytetyn ajan, liikunta-aktiivisuuden ja unen mittaamiseen.

Asiasanat: liikunta, kasvukäyrä, kehityspolkuanalyysi, pitkittäistutkimus, ravinto, istuminen, ruutuaika, uni, tupakointi, alkoholinkäyttö, elinkaari

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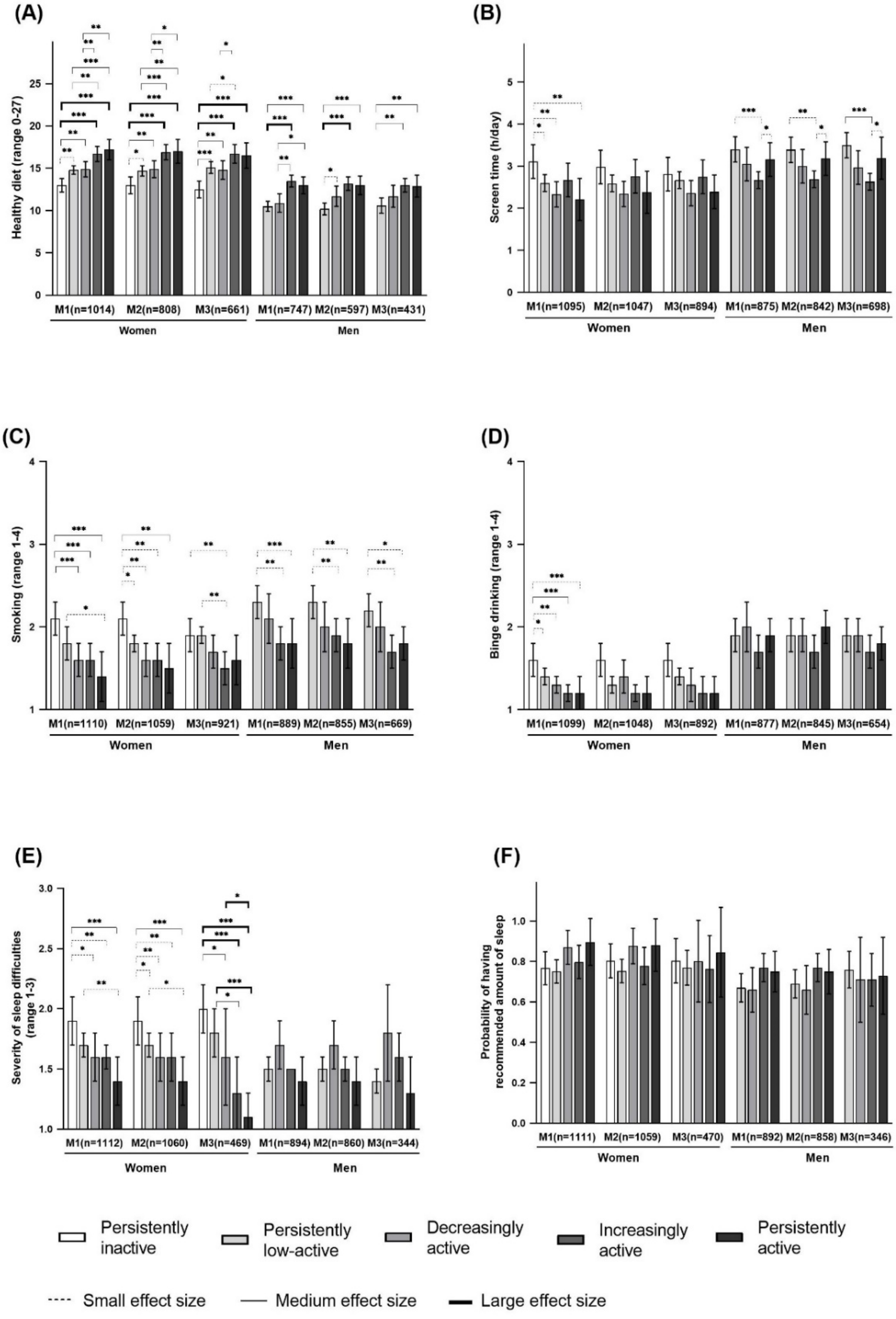
APPENDICES

Appendix 1. Mean values, 95% confidence intervals, p-values, and effect sizes for each health-related behavior across the leisure-time physical activity trajectories in the models 1-3 for women and men aged 33 to 49 years.



Legends for Appendix 1 on previous page: This is a modified version of the original figure 2 in Study IV. A=healthy diet; B=screen time; C=smoking; D=binge drinking; E=severity of sleep difficulties; F=probability of having the recommended amount of sleep; M1=unadjusted model 1; M2=adjusted model 2; M3=adjusted model 3. M2 was adjusted for age, body mass index, education, and marital status and, in addition, diet was adjusted for total energy intake. In M3, each behavior was also adjusted for the corresponding earlier behavior: diet assessed in 1989, screen time in 2001, binge drinking in 1989, smoking in 1989, fatigue in 1986 and sleep duration in 1986. Significant mean differences in each health-related behavior across the LTPA trajectory classes in each model (M1-3) are marked with an asterisk (* = $p<.05$; ** = $p<.01$; *** = $p<.001$) and small (0.20-0.49), medium (0.50-0.79), and large (⩾0.80) effect sizes with different types of lines. *LTPA* Leisure-time physical activity.

ORIGINAL PUBLICATIONS

I

DISTINCT TRAJECTORIES OF PHYSICAL ACTIVITY AND RELATED FACTORS DURING THE LIFE COURSE IN THE GENERAL POPULATION: A SYSTEMATIC REVIEW

by

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Distinct trajectories of physical activity and related factors during the life course in the general population: a systematic review

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Abstract

Background: In recent years, researchers have begun applying a trajectory approach to identify homogeneous subgroups of physical activity (PA) in heterogeneous populations. This study systematically reviewed the articles identifying longitudinal PA trajectory classes and the related factors (e.g., determinants, predictors, and outcomes) in the general population during different life phases.

Methods: The included studies used finite mixture models for identifying trajectories of PA, exercise, or sport participation. Three electronic databases, PubMed (Medline), Web of Science, and CINAHL, were searched from the year 2000 to 13 February 2018. The study was conducted according to the PRISMA recommendations.

Results: Twenty-seven articles were included and organized into three age group: youngest (eleven articles), middle (eight articles), and oldest (eight articles). The youngest group consisted mainly of youth, the middle group of adults and the oldest group of late middle-aged and older adults. Most commonly, three or four trajectory classes were reported. Several trajectories describing a decline in PA were reported, especially in the youngest group, whereas trajectories of consistently increasing PA were observed in the middle and oldest group. While the proportion of persistently physically inactive individuals increased with age, the proportion was relatively high at all ages. Generally, male gender, being Caucasian, non-smoking, having low television viewing time, higher socioeconomic status, no chronic illnesses, and family support for PA were associated either with persistent or increasing PA.

Conclusions: The reviewed articles identified various PA subgroups, indicating that finite mixture modeling can yield new information on the complexity of PA behavior compared to studying population mean PA level only. The studies also provided novel information how different factors relate to changes in PA during life course. The recognition of the PA subgroups and their determinants is important for the more precise targeting of PA promotion and PA interventions.

Trial registration: PROSPERO registration number: CRD42018088120.

Keywords: Physical activity, Sport participation, Exercise, Longitudinal, Prospective, Trajectory, Finite mixture model, Review

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Background

Up to four-fifths of adolescents and one-third of adults do not meet the public health physical activity (PA) recommendations [1]. The high prevalence of physical inactivity imposes a substantial economic burden on health care resources [2, 3]. For these reasons, the promotion of PA should be a standalone public health priority [4]. Studying PA behavior and its correlates longitudinally can help better understand how PA develops and why during the life course.

Previous research has established that overall PA decreases with age and is lower among women [1, 5]. Longitudinal data show that an individual's earlier PA predicts similar PA behavior in the future [6–8], and that PA tracks at low to moderate levels from childhood to adulthood [9]. While tracking shows whether individuals maintain their PA ranking in the study population over time [10], it does not necessarily address the issue of whether they maintain their PA level. As for trajectory approach, it allows study of the development of behavior (e.g., PA level) over time [11, 12]. A trajectory describes the development (stability or change) in an individual's behavior over a relatively long period [11, 13]. Whereas change in time is traditionally studied with two measurement points, trajectory studies use multiple measurement points enabling the study of linear as well as curvilinear change in time [14]. This means that the longitudinal nature of the data can be exploited more thoroughly, and the variation in the magnitude, rate and timing of possible change can be studied more precisely.

While standard growth curve modeling has been applied for studying the mean PA trajectory of a population and how individual variation about that mean relates to predictors [15–17], not until recent years, the number of studies identifying distinct PA trajectory classes (i.e., subgroups) has increased. In these studies, the target behavior of individuals in the same trajectory class is expected to be similar, while it differs from that of the individuals in the other classes [14, 18]. In addition, it is possible to study how potential predictors, determinants and outcomes relate to the distinct trajectories [11, 13, 18, 19]. Identifying distinct PA trajectories at different phases of life as well as examining the factors related to the trajectories is important for planning tailored and well-targeted PA promotion strategies and interventions – especially for those who are inactive or at risk of becoming inactive.

Trajectory classes have been identified using various statistical approaches, such as latent class analyses, latent class growth analyses, growth mixture modeling and group-based trajectory modeling [11, 12, 18–20]. These are all known as finite mixture modeling methods [19, 20]. The strength of finite mixture modeling is that rather than assuming the existence of distinct trajectories in a population, it identifies them based on the population data [11, 13, 14]. Thus, in finite mixture models the number of underlying trajectories, their shape, their prevalence in the population and the assignment of individuals to them are all inferred from the data [12, 20].

However, data on PA trajectories identified in different study populations and the factors that explain why certain individuals follow certain PA trajectories have not yet been assembled. This paper systematically reviews the longitudinal studies that have used finite mixture modeling to identify distinctive PA trajectory classes in the general population at different life phases. The aim is to provide an overview of the research on trajectory classes by gathering and categorizing the data reported on the shapes, proportions and descriptions of trajectory classes, taking into consideration the age of the participants. In addition, the review investigates potential factors (e.g., determinants, predictors and outcomes) associated with specific PA trajectories.

Methods

Protocol and registration

This systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [21], and applying the PRISMA checklist (Additional file 1: Table S1). The review protocol was registered with the International Prospective Register of Systematic Reviews (PROSPERO) and is available from http://www.crd.york.ac.uk/PROSPERO/display_record.php?ID=CRD42018088120 (Registration number: 2018: CRD42018088120).

Search strategy and data sources

Since preliminary searches showed that no articles identifying distinct PA trajectories had been published before the year 2000, the search was conducted from the year 2000 to 13 February 2018. The following databases were systematically searched: PubMed (Medline), Web of Science, and CINAHL. To ensure a comprehensive coverage, a wide range of search terms was used. To be eligible for consideration, articles had to contain a mention of the term *trajectory* and, for each of the following fields, at least one of the italicized terms: (a) for PA: *physical activity, physical inactivity, sport, exercise* or *team participation*; (b) for the study design: *longitudinal, cohort, prospective, panel* or *follow-up;* and (c) for distinct trajectory classes: *group, cluster, class, profile, subgroup* or *classification.* For details on the search strategy, see Additional file 2: Table S2.

Inclusion and exclusion criteria

To be included in the review, studies had to (a) be longitudinal in design; (b) report data on children, adolescents, adults or older adults in the general population;

(c) identify more than one trajectory class with three or more measurement points for either PA, exercise or sport participation (SP); (d) use finite mixture modeling for the identification of trajectories; (e) be published between the year 2000 and 13 February, 2018; and (f) be published in English.

As the purpose of the review was to identify studies specifically using finite mixture modeling, studies using statistical methods where the number of classes was decided a priori or methods that assumed the individuals come from a single population that can be described and approximated adequately with a single growth trajectory (e.g., growth curve modeling), were excluded. Also excluded were studies combining other variables (e.g., other health behaviors) with PA in the same trajectory modeling, conference abstracts without existence of published article, and studies confined to groups with significant co-morbidities (e.g., chronic illnesses, disabilities or mental health problems) or that solely concerned pregnant women.

Study selection process

To establish inter-rater reliability, studies were selected by two authors (IL and KS) independently. First, the titles and abstracts of candidate articles were screened for relevance. After a relevant abstract was found, the full text was assessed for eligibility. Where uncertainties arose about the inclusion of an article, the other authors (AK, MH, AT, and SP) were consulted.

Data extraction

When available, the following data were extracted from each article: reference (authors and publication year), study aims, description of the study (name of the study, geographical location, study design, year of the baseline measurement, follow-up time, and number of measurements), study sample (sample size, distribution of males and females, and age at baseline), statistical approach (the finite mixture model used to identify the trajectory classes, the software used for the analysis, the criteria used for model comparison, determining the final number of trajectory classes, and the goodness of fit of the model), data collection and PA variables, description of the trajectory classes identified (the number and names of the trajectory classes and the proportion of participants in each trajectory class), factors related to the PA trajectories (predictors, determinants, outcomes, and covariates), and main findings in relation to trajectory class membership. One author (IL) performed the data extraction, consulting other authors when needed (MH, AK, KS, THT, and SP).

Quality assessment

Two authors (IL and MH) independently assessed the methodological quality of the included studies. Any disagreement or uncertainty was resolved by consulting a third author (AK). Study quality was assessed by using modified versions of the Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies (https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools) and Guidelines for Reporting on Latent Trajectory Studies (GRoLTS) -checklist [22]. The GRoLTS-checklist is mainly aimed for studies using latent growth mixture modeling and latent class growth analysis, but when modified, is usable for all finite mixture models. The researchers also included some additional criteria for example, objective vs. self-reported measures of PA, whether more than one statistical fit measure was used when deciding the final number of trajectory classes and whether at least one of the fit measures was the Bayesian Information Criterion (BIC) or adjusted Bayesian Information Criterion (ABIC). These criteria were added in response to the recommendation that researchers use more than one comparison tool for deciding the final number of trajectory classes and that the BIC or ABIC should be one of them [22]. The questions chosen for the quality assessment were aimed to assess attrition bias, performance bias, selection bias concerning the final number of trajectory classes chosen, detection bias, and other biases (e.g., were covariates used).

Each included study was rated in quality from zero to 16. The study under assessment was marked “yes” when it met a given quality criterion and “no” when it did not, “NA” when the criterion was not applicable, and “CA” when meeting the criterion could not be determined from the information provided by the study. In addition, if a specific quality criterion was not mentioned in the assessed study but reference was made to previous studies where the criterion was mentioned, it was marked “yes”. Studies scored 1 point for each yes and 0 points for each no, “NA” and “CA”. Study quality was categorized as poor (score ranging from 0 to 5), fair (6 to 11), or good (12 to 16).

Analyses

To summarize the PA trajectory classes identified in the general populations studied and the factors explaining these classes, the relevant data were first extracted from the included articles and a qualitative synthesis, including tables and figures, was performed. The articles were organized into groups based on the participants’ age in each study. Each of the PA trajectories reported in the studies was subsumed under a PA trajectory category that best described the name and shape of the trajectory. To illustrate the proportion of participants within a trajectory class (i.e., class size of the trajectory) and to compare this to the proportions in the other trajectory classes within and between the PA trajectory categories (p), a forest plot was generated. For the forest plot, standard errors (SE) and 95% confidence intervals (95% CI) for the class sizes reported in the individual studies were calculated using the formula $SE = \sqrt{p(1-p)/n}$, where n is the sample size of a study; 95% CI: $p \pm 1.96$ SE. The forest plot was generated using R version 3.2.2 (package forestplot). The results could not be combined in a quantitative synthesis (i.e., meta-analysis) as the inclusion criteria were based on diverse PA, exercise and SP variables and the participants were examined at different phases of life in different studies. The mean age at which PA level started to decrease among children and adolescents was calculated using IBM SPSS Statistics (version 24).

Results

Overview of the included studies

The literature search identified 828 articles and an additional study [23] was added through other sources. After discarding duplicates, 574 potential articles remained. After screening the titles, abstracts, and full texts of the articles independently, the two authors (IL and KS) found that they had each selected the same 27 articles and two different articles each that potentially met the inclusion criteria. Full consensus was reached after discussion and 27 papers were deemed to have fully met the inclusion criteria (Fig. 1; Additional file 3: Table S3). All studies were published between years 2004 and 2018.

Objectively measured PA was available from three different research data and was used in six studies [24–29] while the others used self-reported or parent-reported measures of PA [30–45], exercise [46, 47] and SP [23, 26, 28, 48, 49] (Additional file 3: Table S3). The broader term PA trajectories is used to refer to all the different trajectories of PA, exercise and SP. Specific information is provided separately for PA and SP only for the qualitative synthesis of trajectories during childhood and adolescence and also in Additional file 4.

The number of PA trajectory classes identified in each study ranged from one to five, and was most commonly either four [23, 24, 26–28, 31, 36, 37, 39–41, 46] or three [24–26, 28, 29, 33–35, 42–45, 48, 49] (Additional file 3: Table S3). Eight studies identified separate trajectories for males and females [24, 25, 38, 43, 44, 46, 48, 49], twelve studied males and females together in the same trajectories [23, 26–28, 30–32, 36, 40–42, 45], five studied females only [29, 35, 37, 39, 47], and two studied males only [33, 34].

Overview of study quality and risk of bias

The quality assessment results are shown in detail as supplementary material (Additional file 5: Table S4). Initial agreement on study quality between the two raters (IL and MH) was 90%, and full consensus was reached after discussion. Study quality scores ranged from 9/16 to 15/16 (mean = 12). None of the 27 studies were rated as of poor quality, 11/27 were rated as fair (scores 9: n = 3 [43, 44, 48]; 10: n = 3 [34, 37, 46]; 11: n = 5 [24, 25, 31, 41, 47]), and 16/27 as good (scores 12: n = 3 [38, 40, 45]; 13: n = 2 [23, 32]; 14: n = 3 [36, 42, 49]; 15: n = 8 [26–30, 33, 35, 39]). Frequent reporting on items from the modified Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies was observed [see Additional file 5: Table S4; questions 1–9]. However, reporting on items from the modified GRoLTS-checklist was more infrequent: only ten of the 27 studies reported on all of the six items selected from the GRoLTS-checklist [see Additional file 5: Table S4; questions 11–16] while seven studies reported on just one and three on two items.

Nineteen distinct longitudinal research data were used in the 27 articles (Additional file 3: Table S3). To avoid the reporting of duplicated results, the exact same PA trajectories derived from the same data are treated as one and the same result instead of as separate results [26–28, 43, 44]. The potentially different outcomes, determinants or predictors of all trajectories are still reported separately for each study. Nevertheless, since the review aimed to capture all the different PA trajectory classes thus far identified in general populations, when the shape, class size or the number of PA trajectories identified differed between studies, they were treated as separate results, including when derived from the exact same data.

The age groups and PA trajectory categories derived from the reviewed studies

The studies were organized into three groups based on the participant age: youngest, middle, and oldest (Additional file 3: Table S3; Additional file 4). The youngest group consisted of children, adolescents and young adults, while the oldest group consisted of late middle-aged and older adults. The middle group was mixed, consisting largely of adults with the study period initiated in childhood, adolescence or adulthood and, in some studies, continuing up to old age.

Each PA trajectory reported in the included studies was classified under a PA trajectory category that best described its name, shape, and context (Additional file 4). The middle and oldest groups were distributed across six PA trajectory categories: Increaser, Highly active, Active, Inactive, Decreaser from a moderate PA level, and Decreaser from a low PA level / low-active. In the youngest group, an additional category, labelled Decreaser from a high PA level, was detected, and the Increaser category was replaced with a category labelled From increaser to decreaser. The purpose of the forest plot (Additional file 4) is to provide a comprehensive visualization of the

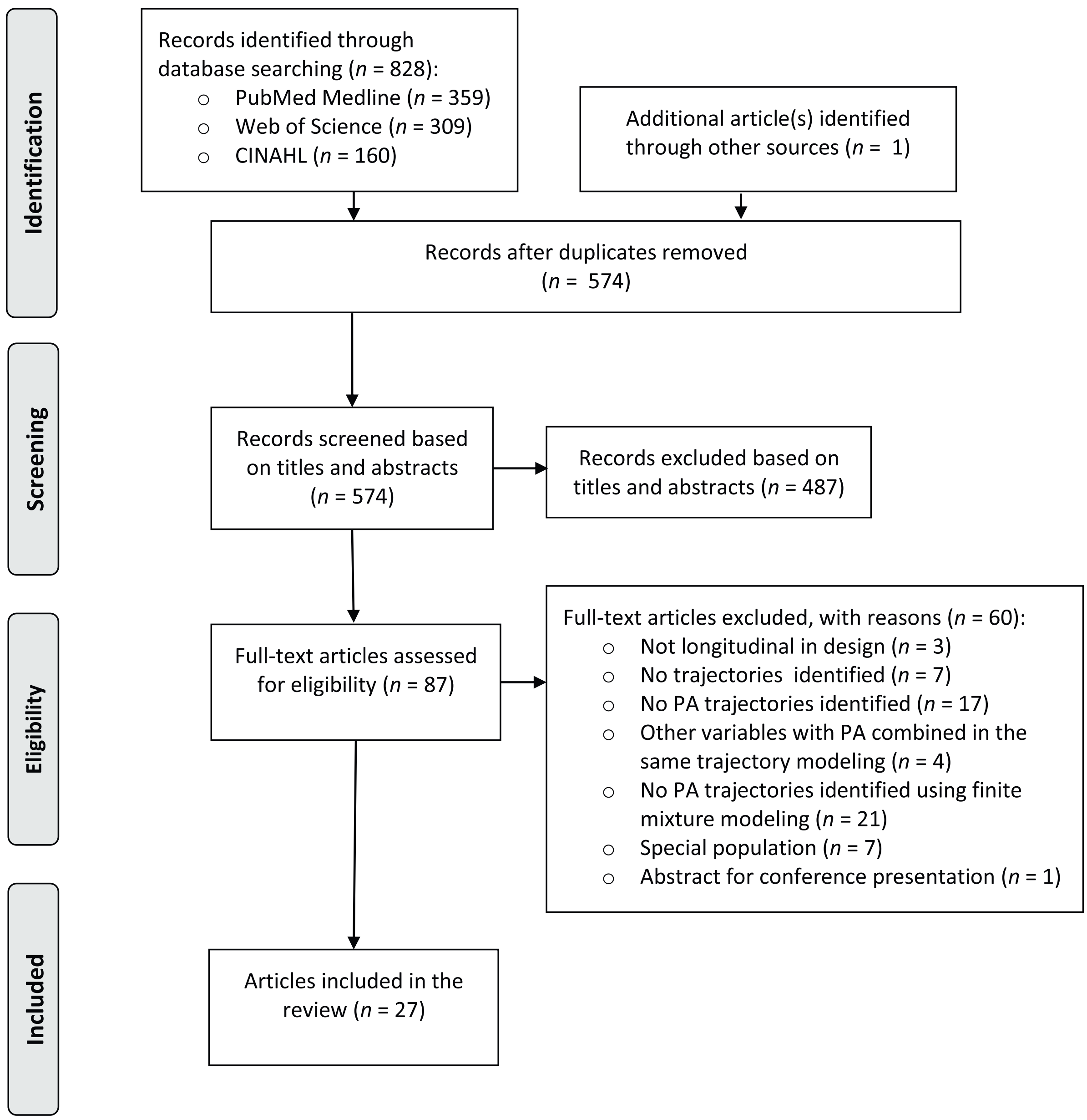

Fig. 1 PRISMA flow chart for the selection of studies. *Abbreviations:* PRISMA = preferred reporting items for systematic reviews and meta-analyses; PA = physical activity

prevalence and class sizes of distinct trajectories in general population at different phases of life. It also summarizes in one figure the sizes of the study samples and the PA measures and data collection method used in each study.

PA trajectories in the youngest group

The youngest group contained 11 articles [23–28, 30, 38, 39, 48, 49] (Additional file 3: Table S3). Participants were aged four to 14 at baseline with the oldest participants aged 22 at the end of the latest follow-up. Follow-up time varied from two to 15 years (mean = 9.3 years; median = 8 years) and sample size from 530 to 8978 participants between studies.

In most studies, the trajectories with the highest proportion of individuals (range 39–100%) were placed in the following PA trajectory categories: Decreaser from a moderate PA level [24, 28, 39], Active [23, 28, 38, 49] or Decreaser from a low PA level / low-active [24, 30, 48] (Additional file 4: c, f, g). Altogether, 53 different PA trajectories were reported in the studies in the youngest group (Additional file 4). Persistent PA was described only in 14 trajectories: 11 in the Active category and three in the Highly active category (Additional file 4: b, c). Analysis of the shapes of the distinct trajectory classes showed that inactivity and low activity were more persistent behaviors [23, 28, 30, 38, 49] than high or moderate activity [23–25, 28, 30, 39, 49], meaning that those following the high or moderate PA trajectories more often showed change (usually a declining change), while the inactives remained at the same level.

More than half of the 53 trajectories described a decline in PA level during childhood and adolescence (Additional file 4: a, e, f, g). In fact, no studies found clear trajectories of continuously increasing PA: even an initially ascending trajectory was followed by a descent (Additional file 4: a). The declining trend in PA was especially clear in studies using objectively measured PA, where as many as 18 of the 21 trajectories described a decline in PA level [24, 25, 28]. Mean age at the start of the decline was 7.7 years in the studies using objective measures [24, 25, 28] compared to 9.6 years in those using self-reports of PA [32, 38, 39] or 10.8 years in those using self-reports of SP [28, 48, 49]. Although decreasing trends were prevalent in the youngest group, the PA level of the decreasers from high or moderate PA did not usually fall to the level of the inactive individuals [24, 30, 38, 48]. However, one study using objectives measures showed that the 95% CIs of all the three declining PA trajectory classes overlapped by the age 17 for girls [25]. Additionally, drop-outs from SP had lower SP rate in young adulthood than those who were initially identified in the non-participation trajectories [28, 49].

PA trajectories in the middle group

The middle group comprised 8 studies [29, 32, 40–45] (Additional file 3: Table 3). Participant age at baseline ranged from 9 to 90. Two studies using the same data identified trajectories from childhood to adulthood [32, 42], another two, using different data, identified trajectories from adolescence to adulthood [43, 44], one studied adults only [45], and the other three studied adults and older adults [29, 40, 41]. Follow-up time varied from two to 34 years (mean = 19.8 years; median = 23.5 years), and sample size from 497 to 3564 participants.

Altogether 28 different middle group PA trajectories were reported in the studies (Additional file 4). In most studies, the largest proportions (range 43–86%) of individuals were in the trajectory classes describing either persistent PA [42–44], inactivity [40] or low PA [29, 32, 45] (Additional file 4: c, d, g). Stable PA trajectories (22 trajectories) were more prevalent than change (i.e., a decrease or increase in PA level) trajectories (6 trajectories) (Additional file 4). In the middle group, the one study measuring PA objectively identified three distinct but stable PA trajectories among women verifying the observation that PA seems to be stable behavior in adulthood [29].

Unlike in the youngest group, three trajectory classes indicating a continuous increase in PA level were reported [32, 40, 41]. One study that identified an increasing PA trajectory from adolescence to adulthood showed that the increasers had very similar PA level as the low-active and inactive participants until the age 12. However, by the age 15 the increasing trajectory began to differ from the low and inactive trajectories with the increase in PA level continuing into adulthood [32]. In two studies, the decreasing PA trajectories did not fall to the level of the inactive trajectories [32, 41] and in one study it did [40].

PA trajectories in the oldest group

Eight studies were placed in the oldest group [31, 33–37, 46, 47] (Additional file 3: Table S3). Age at baseline was 35–55 in one article [31], 40 or older in two articles [33, 47], 50 or older in three articles [35, 36, 46], and 60 or older in two articles [34, 37]. Follow-up time varied from seven to 20 years (mean = 13.9 years; median = 12.0 years) and sample size from 433 to 92629 participants.

Altogether 34 different PA trajectories were reported by the studies in the oldest group (Additional file 4). While seven out of eight studies identified a trajectory describing persistent PA (range 14–51%) (Additional file 4: c), in five studies the highest proportion of individuals (range 26–72%) were in the inactive (Additional file 4: d) [36, 37, 46] and low-active trajectory classes (Additional file 4: g) [35, 47]. In addition, the PA level of those following the decreasing PA trajectories often fell to the level of those following the inactive trajectories [31, 36, 37, 46]. Some studies detected a declining trend in PA level with age, not only in one, but in several trajectory classes [34, 37]. These results show the prevalence of inactivity in older age and how PA levels tend to decline with age. Five studies, however, identified a trajectory class of increasers as well (Additional file 4: a) [31, 33, 36, 46, 47].

Factors related to the PA trajectories

Most studies also aimed to explore what potential factors (i.e., predictors, determinants, and outcomes) are associated with specific PA trajectories. The most commonly studied factors were socioeconomic status (SES), family or social support, sociodemographic characteristics, health behaviors, and health-related variables (Additional file 3: Table S3).

Several studies in all three age groups showed that either higher education, higher income or higher occupational status was associated with a higher probability of following an active rather than inactive trajectory [26, 31–33, 35, 36, 38, 40, 46–48]. Having children was associated with decreasing PA in early midlife [32] while having parental PA support [32] or having a physically active father was an important factor, especially in lower SES families, in the adoption of a physically active lifestyle by a child [26].

Gender differences were observed in PA trajectory membership: active trajectories were more prevalent among males than females [24, 25, 28, 31, 38, 40, 46], just as participation in sport was more frequent among boys than girls [48, 49]. In contrast, the studies using data from Finnish cohorts found no marked gender differences in the membership of the different trajectory classes [43, 44]. Additionally, while Finnish males had higher odds of being persistently active, they also had higher odds of being persistently inactive rather than low active when compared to women [32]. Being non-Caucasian was a risk factor for low PA level [23, 35, 39, 47].

Associations of PA trajectories with other health behaviors were studied in all age groups. Current smoking was associated with decreasing PA, persistently low PA, or inactivity rather than with persistent PA [23, 30, 32, 33, 35, 47], and smoking cessation with increased levels of PA [33]. Greater alcohol consumption was associated with persistent PA [32, 35] and even with increasing PA [33]. Additionally, consistent PA was associated with decreasing television viewing time in adolescence [28, 39]. Older participants with lower fat intake and higher consumption of vegetables and fruits were more likely to follow a physically active than minimally active trajectory [35]. Over-weight and obesity were associated with low activity or inactivity among adult women [29] and older adults [33, 35, 37, 47]. A decreasing PA level in childhood [27] and low SP in adolescence [49] predicted unfavorable changes in body composition in young adulthood while persistent PA in childhood and adolescence predicted a better health profile [49] and greater bone strength [25].

Several different health-related factors were studied, especially among older adults. Older adults with diagnosed chronic diseases (e.g., arthritis, arthrosis, bronchitis, coronary artery disease, chronic obstructive pulmonary disease, or high blood pressure) [33, 35, 37, 47], or who had physical difficulties [47], disabilities [37], depressive symptoms [37, 46], or fair or poor self-rated health [37, 46] were less likely to follow a persistently active trajectory and more likely to follow a low-active or inactive trajectory. In addition, a low mortality rate [37] and good physical functioning [47] were associated with persistent PA. Depressive symptoms were also studied among youth and younger adults. Boys who dropped out from organized sport had higher depression scores at age 20 when compared to consistent sport participants [49]. However, Kaseva et al. found no association between leisure time PA from childhood to adulthood and the progression of depressive symptoms in adulthood.

Discussion

To the best of our knowledge, this systematic review is the first to compile the literature on studies using finite mixture modeling to identify distinct trajectory classes of either stable or changing PA, exercise or SP in the general population during different life phases along with the examination of the potential factors related to these trajectories. The number of studies has started to accumulate: of the 27 included articles, 24 were published from 2010 onward. This reflects the novelty and topicality of the research area. The most common number of trajectory classes reported was three or four (Additional file 3: Table S3). The fact that several PA trajectory classes were identified shows that PA is a behavior that does not develop uniformly between individuals. This is why finite mixture modeling is an appropriate method for studying PA across the life course. Various distinct decreasing PA trajectories were reported among youth, in particular, while among adults and older adults few studies found increasing PA trajectories. The results were in agreement with previous findings showing that the proportion of inactive individuals is rather high at all ages and that inactivity tends to increase with age [1]. Various factors explaining the differences in PA level between individuals during the life course were studied, the strongest associations being found for SES and gender.

Developmental trajectories of PA during the life course

The number of distinct PA trajectories describing change were more prevalent among youth, while persistently stable PA trajectory classes were more prevalent in adulthood. The inactive trajectories seemed to be more stable than the trajectories describing activity. These findings support research showing that low activity and inactivity track better than activity, and that the stability of tracking is higher during adulthood than in childhood or during the transition from childhood to adolescence or from adolescence to adulthood [9]. However, the trajectory studies reviewed here add to these findings by showing what specific changes in PA level occur between individuals during the life course.

All the reviewed studies in the youngest group identified at least one distinct PA trajectory describing a decrease in a high, moderate or low level of PA, a curvilinear trajectory describing an increase followed by a decrease in PA [24, 25, 28, 30, 38, 39], or drop-out from SP [23, 28, 48, 49]. This result is in line with previous findings showing that childhood [50, 51] and adolescence [52–54] are periods of life characterized by a decline in PA. Interestingly, the reviewed studies using objective measures of PA found that the level of PA had already started to decline at the age of school entry [24, 25, 28] whereas the studies using self-reported measures of PA found the corresponding age to be around 10 years [32, 38, 39]. It should be pointed out that some of the studies using self-reported measures studied slightly older children than the studies using objective measures, a factor that could partially explain this difference. However, regardless of measurement type, the trajectory studies showed that PA starts to decline in childhood, and not in adolescence – an observation also emphasized in other reports based on objectively measured PA [51, 55]. However, drop-out from SP might be more common in adolescence than in childhood since the age at which the decline began was higher in the SP than PA trajectories [23, 28, 48, 49].

While no trajectory classes characterized by consistently increasing PA were observed in the youngest group, such classes were reported in few of the studies in the middle [32, 40, 41] and oldest [31, 33, 36, 46, 47] groups. In the oldest group, the participants were younger in the five studies identifying a trajectory of increasing PA [31, 33, 36, 46, 47] than those in the three studies reporting no such trajectories [34, 35, 37]. Nguyen et al. [35] found a minimal but significant increase in PA over time in their moderately and highly active trajectory classes among 50- to 69-year-old women whereas a slight decrease was observed in PA in each parameter over time among the oldest participants (70 years or older). Various explanations have been offered for this. It has been suggested that adults increase their PA level due to aging-related health concerns [56, 57] or after retirement [58–60], while overall PA tends to eventually decline with older age [1], possibly due to declining health [60]. In most of the reviewed studies examining older adults [31, 36, 37, 46], those in the declining PA trajectories eventually approximated to the PA level of those in the inactive trajectories [31, 36, 37, 46]. At the same time, the declining trajectories usually did not fall to the level of the inactive trajectories in the studies examining children and adolescents [24, 30, 38, 48] or adults [32, 41]. Thus, despite of the common declining tendency of PA throughout life course, being physically active in childhood and adolescence may be of high importance since it can postpone the time of becoming inactive later on.

Factors related to PA trajectory class membership

Various predictors, determinants, covariates and outcomes of PA trajectory class membership were studied. Mostly, these findings further supported other findings that have shown how: (1) higher SES is associated with PA in youth [61–63] and in adulthood [55]; (2) having family support [54, 61], active parents [61, 64], and especially an active father [63, 65], is associated with PA in childhood; and (3) males are generally more active than females [1, 54, 56, 64, 66]. One gender-related exception was found in studies on the Finnish population: leisure time PA was as common among adult women as among men [32, 43], a finding that has also been reported in a study not included in this review [67]. Most of the present results [33, 35, 37, 46, 47, 49] also further supported other findings showing that lack of PA is a major risk factor for morbidity and premature mortality [68–70]. However, one reviewed study found that Caucasian participants in a trajectory labeled "exceeding PA guidelines three times" had higher odds for developing subclinical coronary artery disease by middle age than those in the trajectory "below PA guidelines" [45], suggesting that extremely high doses of leisure time PA might be a risk factor for cardiovascular health.

Thus, most of the present results specifically supported other findings on correlates of persistent inactivity or persistent PA. Apart from studying stable PA trajectories, finite mixture modeling has the advantage of detecting changes over time enabling also the study of factors associated with these changes. The reviewed [23, 30, 32, 33, 35, 47] and other studies [71, 72] have found a negative association between regular smoking and PA with the reviewed studies showing that smoking cessation [33] and non-smoking [32] were associated with increasing PA, whereas an increase in smoking was associated with decreasing PA [30]. While the association between television viewing time and PA has been found to be negative and rather small [73, 74], the present trajectory studies add to this finding by suggesting that persistent PA is associated with decreasing television viewing time [28, 39] whereas decreasing PA is associated with increasing television viewing time [39] in adolescence. Moreover, alcohol consumption was positively associated with both increasing [32, 33] and decreasing PA trajectories [32] rather than with persistently low PA. Rovio et al. [32] also found that having children was associated with membership of a decreasing PA trajectory, an association also observed elsewhere [75]. Groups disadvantaged with respect to education and income were significantly more likely to be on a decreasing than active trajectory [40], while high adulthood education was associated with membership of both increasing and decreasing active trajectories [32]. Special attention should be paid to success at school and parental PA support in childhood since they were both associated with membership of a consistently increasing PA trajectory which began to differ from the inactive and low-active trajectories after the age of 12 [32].

Limitations

This review also has its limitations that could induce bias in interpretation of the results. Gathering and comparing the findings was challenging due to the heterogeneity in study populations, sample sizes, follow-up duration, measurement times, time between measurements, participants' age, the names researchers gave to their trajectories, measurements (PA, exercise, and SP), exposures and outcome variables, data organization in trajectory modeling (i.e., age vs. measurement year), and the finite mixture models used. For example, if the population in one study had lower SES than the populations in other studies, it could be expected to contain a larger group of inactive individuals. The length of the follow-up and the time between measurement points have been found to affect the number of trajectories identified [22], for example, a long interval between measurement points might mean that some PA patterns are not detected. Also, since the trajectory classes were usually labelled in relation to the other trajectory classes identified within each study and not necessarily in relation to PA guidelines, it is possible, for example, that a PA level reported as high in one study might be reported as moderate in another study.

Although articles reporting findings based on the exact same trajectories were omitted, a risk of reporting partially overlapping results remains when PA trajectories were initially identified by gender and then again for both sexes combined [25, 28, 36, 46], or when studies used the same data and variables but diverged over the final number of trajectory classes [32, 42]. The explanation for the latter case might be that Kaseva et al. [42] used Akaike's Information Criterion (AIC) indices, despite the current recommendation that the BIC and ABIC are the best model fit measures for determining the final number of classes compared to, for example, the AIC or Lo-Mendel-Rubin-likelihood ratio test [22]. There is a possibility for selective bias in the final number of trajectory classes when the researchers estimated the shape of the trajectory only up to quadratic shape in studies having more than three measurement points [24, 28, 36–39, 41, 42, 48] which would also enable the estimation of, for example, cubic shape. The possibility of selective bias also exists when classes containing less than 5% of the study population were ignored [30, 33]. Other factors relating to bias at the individual study level are listed point by point in the additional material (Additional file 5: Table S4).

While finite mixture modeling has its advantages, presented in the beginning of this review [11, 12, 22], the developers of the modeling also have recognized the uncertainties related to these models, and a few studies have recommended caution when using them [20, 76–78]. For example, the correct assignment of individuals to a trajectory class cannot be certain, the number of trajectory classes is not immutable [76], and the choice of the optimal number of classes is based on various formal and informal criteria [20]. Thus, while model fit indices (e.g., BIC and ABIC) are available for determining the optimal number of classes, researchers also rely on the share of cases assigned to the smallest trajectory class, interpretability, and model convergence [19, 20]. The observations of this review support these comments that no consensus has not yet been achieved in the use of statistical approaches for identifying developmental trajectories [20, 78] and that the selected statistical approach itself may have an effect on the results [20]. The GRoLTS-checklist has been developed to address these uncertainties; even so, researchers should be alert to new developments in this rapidly evolving area [22].

Future studies

Physical inactivity is the fourth leading risk factor for mortality worldwide [70]. To counter inactivity, future research should pay special attention to identifying additional determinants of trajectory class membership (e.g., social capital, environmental, psychological and genetic factors, cultural and social norms, global media and marketing, urbanization, sleeping, dietary behavior, and other life changes). Special attention should be paid to those who increase their PA, as it is important to understand how potential lifelong inactivity could be reversed to activity. The lack of longitudinal trajectory studies on the transition from adolescence to adulthood needs to be addressed to more profoundly. In addition, more large-scale population-based longitudinal studies using objective measures for identifying PA trajectory classes are needed as objectively measured and self-reported PA have shown only modest agreement [79]. Since all the reviewed studies were conducted in high-income countries (in Europe, USA, Canada, Australia or Taiwan), there is a need to identify PA trajectories in low- and middle-income countries. Finally, specification of the most suitable statistical model for identifying PA trajectories would help in collectively building knowledge in this field. Before this is achieved, use of the GRoLTS-checklist [22] is recommended in future trajectory studies using finite mixture modeling for standardizing the results.

Conclusions

This review supports earlier findings on the general trends and population means of PA during the life course. However, studying diverse trajectory classes using finite mixture modeling also adds to previous knowledge by providing evidence of the heterogeneity of PA. Thus, this review broadens understanding of the variation that occurs in the timing, rate and magnitude of PA development during the life course and the factors relating to membership of specific trajectory classes. This helps identify the key periods of life and key groups at which to target PA promotion and thereby contribute to improving public health. The results showed that PA begins to decline already in childhood, that the PA habits stabilize with age and that inactivity is more persistent than activity. Hence, PA interventions should be targeted at children early in life before their PA habits become stable. Due to the heterogeneity in samples, finite mixture models, exposures and outcome variables used in the selected studies, and the general reliance on self-reported PA, the results of this review need to be interpreted cautiously.

Additional files

Additional file 1: Table S1. PRISMA checklist. (PDF 304 kb)

Additional file 2: Table S2. Details of the search strategy. (PDF 247 kb)

Additional file 3: Table S3. Characteristics of the included studies, physical activity trajectories and related factors reported, and main findings in each study. (PDF 462 kb)

Additional file 4: Forest plot. Physical activity trajectories divided into categories by age group. (PDF 264 kb)

Additional file 5: Table S4. Quality assessment checklist and quality scores of the included studies. (PDF 180 kb)

Abbreviations

ABIC: Adjusted Bayesian information criterion; AIC: Akaike's information criterion; BIC: Bayesian information criterion; CI: Confidence interval; GRoLTS: Guidelines for reporting on latent trajectory studies; n: Number of cases; PA: Physical activity; PRISMA: Preferred reporting items for systematic reviews and meta-analyses; PROSPERO: International prospective register of systematic reviews; SE: Standard error; SES: Socio-economic status; SP: Sport participation

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Availability of data and materials

All values used in this systematic review are gathered from the included articles [23–49] that are available in the following databases: PubMed (Medline), Web of Science, or CINAHL. If needed, the values used and analyzed during the current review are available from the corresponding author on a reasonable request. No individual participant or patient data was used in this review.

Authors' contributions

All authors (IL, KS, AK, MH, SP, AT, XY and THT) made contributions to the conception of the study and were involved in designing it. IL, KS, MH, AK, AT, THT and SP contributed to the development of the selection criteria, and IL, AK and MH to the development of the quality assessment. IL developed the search strategy. IL and KS systematically searched for relevant literature. IL extracted the data from the articles, interpreted it and wrote the manuscript. AK and AT provided statistical expertise. All authors (IL, KS, AK, MH, SP, AT, XY and THT) critically revised drafts of the paper, and read and approved the final manuscript.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Additional file 1: Table S1. PRISMA checklist.

Section/topic	#	Checklist item	Reported on page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	1
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	1
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	2
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	2
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	2
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	2-3
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	2
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	2 + Additional file 2: Table S2
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	2-3
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	3
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	3
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	3
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	3-4
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	3-4

Section/topic	#	Checklist item	Reported on page #
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	3
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	not applicable
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	4 + Figure 1
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	4-7 + Additional file 3: Table S3
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	4 + Additional file 5: Table S4
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	Additional file 4
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	not applicable
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	4, 8-9
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	not applicable
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	7-8
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	8-9
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	9-10
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	10

From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097. For more information, visit: **www.prisma-statement.org**.

Additional file 2: Table S2. Details of the search strategy.

#	Searches
1.	trajector*
2.	physical activit*
3.	physical inactivit*
4.	sport
5.	sports
6	exercise
7.	exercises
8.	team participation
9.	2 or 3 or 4 or 5 or 6 or 7 or 8
10.	longitudinal
11.	cohort
12.	prospective
13.	panel
14.	follow-up
15.	follow up
16.	10 or 11 or 12 or 13 or 14 or 15
17.	group
18.	groups
19.	cluster
20.	clusters
21.	class
22.	classes
23.	profile
24.	profiles
25.	subgroup
26.	subgroups
27.	classification
28.	classifications
29.	17 or 18 or 19 or 20 or 21 or 22 or 23 or 24 or 25 or 26 or 27 or 28
30.	1 and 9 and 16 and 29

'*' indicates truncation.

NB: All search terms were adjusted for the requirements of the different databases. The time was limited from the year 2000 to 13 February 2018, but no other limitations were set concerning the document types or language with the search strategy.

Additional file 3: Table S3. Characteristics of the included studies, physical activity trajectories and related factors reported, and main findings in each study.

Ref.	Aim of the study	Name of the study; geographical location; study design; year of the baseline measurement; follow-up time; number of measurements	Study sample; age at baseline	Finite mixture model used for identifying trajectories; software used; criteria used for model comparison, determining the final number of trajectory classes and goodness of fit of the model	Method for collecting PA data; PA variables used	Number and names of the identified PA trajectory classes, and the proportion of participants in each trajectory class	Determinants / predictors / confounders / mediators / outcomes / covariates of trajectory class membership	Main findings in relation to trajectory class membership
Articles in the youngest group (children, adolescents and young adults)								
Audrain-Mc-Govern et al. (2012)	1) Examine how variation in adolescent PA is associated with smoking and alternative tobacco use.	NR; USA; longitudinal study; NR; 4 years; 8	1429 adolescents (50% females, 73% White); 14 years	GGMM; Mplus; the proportion of cohort members in each class > 5%, BIC, ABIC, entropy*, BLRT	SR; MVPA was defined as sum score of hours / week in activities ≥ 3 METs	Five MVPA trajectories: 1) stable higher PA, 21% 2) decreased PA, 12% 3) stable regular PA, 15% 4) curvilinear PA, 5% 5) stable low PA, 47%	Outcomes: smoking, and alternative tobacco use Covariates: gender, race, and parental education	Adolescents following the stable regular, stable low or decreasing PA trajectory had at least twice as great likelihood of smoking compared to those following the stable high PA trajectory. The prevalence of alternative tobacco use was the greatest among adolescents following decreased and stable regular trajectories at the age of 18 years. Adolescents whose PA significantly declined did not fall below the recommended level of PA but the decreasing PA trajectory had the greatest proportion of regular smokers and alternative tobacco users.
Farooq et al. (2017)	1) Identify when changes in PA take place during childhood to adolescence.	Gateshead Millenium Cohort Study; North-East England; longitudinal study; 2006–2007; 8 years; 4	545 children and adolescents (52% females); 7 years	GBTM; Stata Traj plugin; BIC, posterior probabilities, determining the final number of trajectories was stopped when substantial improvement in model fit was no more found	OBM; Total volume of PA and MVPA were measured using ActiGraph GT1M accelerometers (MVPA= 574 or more counts / 15 seconds)	One trajectory of total volume of PA, females: 1) decreasing, 100% Three trajectories of total volume of PA, males: 1) high decreasing, 10% 2) moderate decreasing, 36% 3) low decreasing, 54% Three trajectories of MVPA, females:	NA	Total PA volume declined already by age seven. It was suggested that greater emphasis should be put to PA promotion already in childhood.

						1) high initial MVPA with steeper declines, 19% 2) gradually declining, 62% 3) low and relatively stable with modest declines, 19% Four trajectories of MVPA, males: 1) initially high and rapidly declining, 17% 2) relatively high and stable or increasing, 19% 3) gradually declining, 62% 4) low and relatively stable / slowly declining, 3%		
Findlay, Garner & Kohen (2009)	1) Identify distinct trajectories of organized PA participation among children and youth. 2) Explore the association of PA trajectories with potential risk factors.	National Longitudinal Survey of Children and Youth; Canada; longitudinal study; 1994; 8 years; 5	8817 children and adolescents (51% females); 4–11 years	Multiple trajectory modeling, semiparametric GBTM; SAS Proc Traj; BIC, posterior probabilities (majority of groups >0.7), all slope parameters had to be statistically significant	PR & SR; Organized PA participation was measured with two questions concerning the frequency of engagement to organized PA	Three trajectories of organized PA participation, females: 1) high decreasing participation, 37% 2) moderate stable participation, 24% 3) low decreasing participation, 39% Three trajectories of organized PA participation, males: 1) high decreasing participation, 32% 2) low decreasing participation, 42% 3) high stable participation, 26%	Predictors: household income, parents' educational level, urban versus rural dwelling, and dual versus single parent at home	The decreasing trajectories of organized PA tended to peak in middle childhood (around 9 to 12 years of age) and then declined into adolescence. For boys and girls, higher parental education and income were associated with a greater likelihood of weekly participation in organized PA. Additionally, living in an urban area was significantly associated with a greater likelihood of weekly participation for girls.
Findlay, Garner & Kohen (2010)	1) Identify distinct trajectories of unorganized PA for children aged 4–17 years. 2) Study the association of PA trajectories with	National Longitudinal Survey of Children and Youth; Canada; longitudinal study; 1994; 8 years; 5	8978 children and adolescents (50% females); 4–11 years	Semiparametric GBTM; SAS Proc Traj; BIC, all slope parameters had to be statistically significant, posterior probabilities (>0.7)	PR & SR; Participation in unorganized PA was measured with one question concerning the frequency of participating in unorganized sports or PA outside of school	Two trajectories of unorganized PA, females: 1) regular participation, 57% 2) infrequent and decreasing participation, 43%	Predictors: household income, parents' educational level, single versus dual parent at home, and urban versus rural dwelling	Boys followed relatively stable trajectories of unorganized PA from childhood to adolescence while a group of decreasers was identified in girls. Out of the examined predictors, parents' higher educational level and having two parents at home predicted regular participation in unorganized PA, but only for boys.

	socioeconomic factors.					Two trajectories of unorganized PA, males: 1) regular participation, 69% 2) infrequent participation, 31%		
Howie et al. (2016)	1) Identify trajectories of organized SP from early childhood to late adolescence. 2) Explore the association of PA trajectories with physical and mental health outcomes in young adulthood.	Western Australian Pregnancy Cohort Study; Australia; longitudinal study; expecting mothers were recruited between years 1989-1991; 15 years; 6	1679 participants (49% females); 5 years	Repeated-measures LCA; LatentGOLD; BIC, AIC, BLRT, posterior probabilities (>0.7), entropy, classification errors, the percent of iterations converging on the same solution, meaningfulness of the solutions, odds of correct classification greater than five	PR; SP was measured with a question whether a child participated in organized sport outside of school hours (yes / no)	Three trajectories of organized SP, females: 1) consistent sport participators, 48% 2) sport dropouts, 34% 3) sport nonparticipators, 18% Three trajectories of organized SP, males: 1) consistent sport participators, 55% 2) sport dropouts, 37% 3) sport joiners, 8%	Outcomes: self-reported PA, body composition, self-rated health, self-rated well-being, mental health, mother's and father's race, and mother's educational level at the age of 20 years Covariate: PA levels at the age of 20 years (total MET-minutes per week)	SP started to decrease at the end of 14 years in the consistent SP trajectories. A nonparticipation trajectory was identified only for girls, suggesting that girls probably should start SP before reaching the age of 8 years. Differences were found in health outcomes between trajectory classes, e.g. boys and girls with consistent SP had more preferable health outcomes, and boys with consistent SP had higher levels of PA at the age of 20 years. However, it is unknown whether SP caused improved health in young adulthood or whether SP was indicative of an overall positive health pattern.
Janz et al. (2014)	1) Identify trajectories of objectively measured MVPA from childhood to adolescence. 2) Study whether MVPA predicts bone strength.	Iowa Bone Develop-mental Study; USA; longitudinal study; 1998–2002; 15 years; 6	530 participants (50% females, 95% White); 5 years	LCA: SAS Proc Traj; BIC, individual-specific probabilities	OBM; MVPA was measured using ActiGraph accelerometers (MVPA = 2296 or more counts / min)	Three MVPA trajectories, females: 1) severely declining high activity, 6% 2) declining moderate activity, 45% 3) declining persistent inactivity, 50% Three MVPA trajectories, males: 1) increasing high activity followed by a decline, 23% 2) increasing moderate activity followed by a decline, 37% 3) declining persistent inactivity, 40%	Outcome: bone strength (dual X-ray energy absorptiometry and peripheral computer quantitative temography) measured at the age of 17 years Covariates: weight and height	The proportion of highly active children was very low, especially among girls. By the age 17 almost all girls, including girls from the once highly active group, were inactive. A persistently high PA level during childhood was significantly associated with greater bone strength among adolescent boys and girls even after reductions in PA level during adolescence.
Kwon, Lee & Carne-thon (2015)	1) Identify PA and television viewing trajectories among adolescent girls. 2) Demonstrate the risk factors (race) of PA trajectories.	National Growth and Health Study; USA; longitudinal study; 1987; 9 years; 7	2155 African-Americans (100% females, 52% Black); 9–10 years	LCGA, GBTM, dual-trajectory analyses; Stata Traj; BIC, trajectory shapes for similarity, odds of correct classification >5.0, the proportion of cohort members	SR; The sum of Habitual Activity Questionnaire scores for different activity categories (expressed as MET-times per week) was used as an indicator for the level of PA	Four PA trajectories, females: 1) substantially decreasing from high PA, 9% 2) maintaining moderate PA, 32%	Predictor: race Outcome: television viewing	Eighty-eight per cent of the girls maintaining high PA level followed the decreasing television viewing trajectory, whereas 86% of the girls following the decreasing moderate PA trajectory also followed the increasing television viewing trajectory. A significantly lower proportion of Black girls followed the

	3) Study the relationship between PA and television viewing trajectories.			assigned in each class (needs to be close to the proportion estimated from the model), posterior probabilities (>0.7), interpretation of 99% confidence intervals		3) maintaining high PA, 6% 4) decreasing from moderate PA, 53%		maintenance PA trajectories than White girls.
Kwon et al. (2015a)	1) Identify distinct MVPA trajectories from 5 to 19 years. 2) Examine the associations of MVPA trajectories with SP and television viewing trajectories.	Iowa Bone Development Study; USA; longitudinal study; 1998–2002; 15 years; 7	537 participants (50% females, 95% White); 5 years	GBTM; Stata Traj; BIC, similarity of trajectory shapes, the proportion of participants in each class (needs to be close to the proportion estimated from the model), odds of correct classification >5.0, posterior probabilities (>0.7), interpretation of 99% confidence intervals	OBM for MVPA; MVPA was measured using ActiGraph accelerometers (MVPA = 2296 or more counts / min). SR for SP; Participants who reported participating in at least one eligible sport were categorized as participating in organized sports (during the last six months at 1st measurement and during previous seven days at 2nd measurement).	Four MVPA trajectories: 1) consistently inactive, 15% 2) consistently active, 18% 3) decreasing moderate MVPA, 53% 4) substantially decreasing high MVPA, 14% Three SP trajectories: 1) no SP, 14% 2) drop-out from SP, 40% 3) consistent SP, 46%	Outcomes: SP and television viewing Covariate: sex	Four MVPA trajectories, three SP trajectories and four television viewing trajectories were identified. Especially girls' inactivity was persistent from childhood to adolescence. The participants following the consistently inactive trajectory also followed a trajectory of no SP. The consistently active trajectory was significantly associated with decreasing an already low television viewing time. SP could be one way to prevent a consistently inactive pattern.
Kwon et al. (2015b)	1) Study whether following certain MVPA trajectories during childhood and adolescence predicts different risk levels of becoming obese in young adulthood.	Iowa Bone Develop-mental Study; USA; longitudinal study; 1998–2002; 16 years; 7	493 participants (51 % females); 5 years	GBTM; Stata Traj; BIC, posterior probabilities (>0.7), the proportion of cohort members in each class, similarity of trajectory shapes, odds of correct classification (≥5.0), the proportion of a sample assigned to a certain group close to the proportion estimated from the model, interpretation of 99% confidence intervals	OBM; MVPA was measured using ActiGraph accelerometers (MVPA = 2296 or more counts / min).	Four MVPA trajectories (identified earlier in Kwon et al. 2015a): 1) consistently inactive, 15% 2) consistently moderately active, 18% 3) decreasing from a moderate level of MVPA, 53% 4) substantially decreasing high level of MVPA, 14%	Outcome: obesity in young adulthood (percentage of body fat measured with whole body dual-energy X-ray absorptiometry) Covariates: sex, maternal education level, age of peak height velocity, and energy intake	Participants who were active as children but became less active with age were more likely to become obese in young adulthood when compared to consistently active participants.
Kwon et al. (2016)	1) Identify different latent classes of relationships among parental factors (family income,	Iowa Bone Development Study; USA; longitudinal study; 1998–2002; 15 years; 7	408 families, n=537 for MVPA trajectories (48% of children	GBTM; Stata Traj; BIC, posterior probabilities, similarity of trajectory shapes, proportion of cohort members in each class	OBM for MVPA; MVPA was measured using ActiGraph accelerometers (MVPA = 2296 or more counts / min).	Four MVPA trajectories (identified earlier in Kwon et al. 2015a): 1) consistently inactive, 15%	Predictors: family support for PA, and variables of parental characteristics that correlate with child's PA behavior	More favorable PA and SP behaviors were observed among those in higher SES families and with higher PA engagement of parents. However, youth in the parental factor class described as having low family SES and regular PA in high school by the father tended to

	educational level, parents' regular PA in high school and adulthood). 2) Examine the influence of the parental classes on child's SP and MVPA trajectories. 3) Study if family support mediates the influence of parental patterns on child's SP and MVPA trajectories.		were females; 97% White); 5 years		SR for SP; Participants who reported participating in at least one eligible sport were categorized as participating in organized sports (during the last six months at 1st measurement and during previous seven days at 2nd measurement).	2) consistently active, 18% 3) decreasing moderate physical activity, 53% 4) substantially decreasing high physical activity, 14% Three SP trajectories (identified earlier in Kwon et al. 2015a): 1) no SP, 14% 2) drop-out from SP, 40% 3) consistent SP, 46%	Covariate: sex	follow the consistent SP trajectory. Thus, among lower SES families, the father's role may be important to promote youth to sustain SP. Family support was independently associated with participant's PA behavior, rather than mediating the influence of parental factors on child PA.
Rod-riguez & Audrain-Mc-Govern (2004)	1) Study the likelihood of smoking at 11th grade among adolescents following distinct trajectories of team sport participation.	NR; USA; longitudinal study; 2000; 2 years; 4	1098 high school students (52% females); 14 years	GGMM; Mplus; BIC, entropy	SR; Team participation was assessed on a 4-point scale describing the number of teams on which the participant played during the past 12 months	Four team participation trajectories: 1) erratic, 7% 2) decrease, 13% 3) high, 41% 4) low, 39%	Outcome: smoking at 11th grade Covariates: gender, race, baseline smoking, baseline alcohol use, baseline PA, baseline extracurricular activity, baseline depressive symptoms	Adolescents following the decreasing and erratic team participation trajectories were more likely to smoke in grade 11 than individuals with high participation. Females were at high risk for following the low trajectory while non-whites were at high risk for following the decreasing and erratic trajectories.
Articles in the middle group (mainly adults)								
Barnett et al. (2008)	1) Identify LTPA trajectories. 2) Explore socioeconomic and demographic predictors of distinct LTPA trajectories.	Canada Fitness Survey 1981 / Campell's Survey of Well-being 1988 / Physical Activity Longitudinal Study 2002–2004; Canada; follow-up cohort study; 1981; 22 years; 3	884 adults (56% females); 18–60 years	LCGA, semi-parametric GBTM; SAS Proc Traj; BIC, assignment to the class with highest prior probability	SR; LTPA was measured with questions concerning frequency and duration of activities. Average daily energy expenditure was computed and expressed in kcal / kg / day.	Four LTPA trajectories: 1) inactive, 56% 2) increasers, 25% 3) active, 12% 4) decreasers, 7%	Predictors: age, sex, degree of urbanization at baseline, highest reported education, and baseline family income	Socio-economic and demographic factors strongly predicted the probability of following certain LTPA trajectories. Older participants, females, those having lower household income, and with lower educational level were significantly less likely to follow active than inactive trajectories. Additionally, those having lower educational level and lower household income were significantly more likely to follow decreasing than active trajectory.
Dishman et al. (2010)	1) Identify trajectories of meeting a	NR; Hawaii; longitudinal	497 adults (64%	LCGA; Mplus; Vuong-Lo-Mendell Rubin likelihood ratio	SR; PA is expressed as MET-minutes / week. METs were used for	Four trajectories of meeting the recommendations for	Predictors: initial baseline values and change in	Constructs of Transtheoretical model can be used for predicting possible changes in PA behavior. Those

	guideline for sufficient participation in health-promoting PA. 2) Model longitudinal change in constructs of the Transtheoretical Model. 3) Study the association of the changes in the constructs of the Transtheoretical Model with the PA trajectories.	study; NR; 2 years; 5	females; 32% Asian; 19% Native Hawaiian / Pacific Islander; 40% Caucasian; 8% Other); 18–90 years (mean = 49 years)	test, likelihood probability	categorizing people as meeting or not meeting the public health guidelines for sufficient regular PA.	participation in regular MVPA: 1) always met, 23% 2) not met to meeting, 19% 3) partially met - declining, 34% 4) never met, 24%	constructs of the transtheoretical model including experiential and behavioral processes Covariates: gender, age, race, education level, median annual household income, marital status, BMI	participants maintaining or attaining the PA guideline more likely retained higher scores in the variables of Transtheoretical model (except self-efficacy). Participants used experiential as well as behavioral processes when trying to increase or maintain their PA level.
Kaseva et al. (2016)	1) Identify distinct PA trajectories from childhood to adulthood. 2) Study the associations of PA with changes in depressive symptoms in adulthood.	Young Finns Study; Finland; longitudinal study; 1980; 31 years; 8	3596 at baseline, n=3564 for the PA trajectories (51% females); 9–18 years	LCGA; Mplus, and Stata; AIC, posterior probabilities (>0.7), practical consideration	SR; LTPA was measured with several questions (e.g., frequency and intensity of PA, participation in organized PA, participation in sport competitions, habitual way of spending leisure-time, frequency of vigorous PA, hours spent on vigorous PA, and average duration of PA session) between ages 9 and 49 years. LTPA index was created based on these questions.	Three trajectories of LTPA: 1) highly physically active, 4% 2) moderately physically active, 86% 3) lightly physically active, 10%	Outcome: depressive symptoms in 2012 Covariates: age, sex, BMI, participants' negative emotionality in childhood, parents' educational and income levels, participants' adulthood depressive symptoms (in 1992, 1997, 2001, and 2007), participants' educational and income levels, participants' experiences of social support, and smoking status	A decline in PA was seen in each activity trajectory. Higher PA level was associated with lower levels of depressive symptoms in adulthood when compared to lower PA level, however, the association disappeared when covariates were taken into account. Thus, PA from childhood to adulthood or PA in adulthood was not associated with the progression of depressive symptoms in adulthood.
Kim et al. (2016)	1) Identify distinct PA trajectories among women. 2) Study the correlates of PA trajectory class membership.	Women's Injury Study; Southwest Central region of USA; prospective cohort study; 2007–2008; 5 years (18	669 adults (100% females); ≥20 years (mean = 53 ± 13 years)	LCGA; SAS and Mplus; ABIC, entropy, posterior probabilities, Lo-Mendell-Rubin likelihood ratio test	OBM; PA was measured using Accusplit 120XL-xBX pedometers across 18 consecutive months. The participants reported the step-count data via web-based surveillance in 7- or 8-day intervals.	Three trajectories of PA, females: 1) active (10000–12499 steps / day), 12% 2) somewhat-active (7500–9999 steps / day), 41% 3) low-active (5000–7499 steps / day), 47%	Covariates: age, race, marital status, family income, employment status, cardiovascular-related problems, bone-related problems, and percent of body fat	Relatively high proportion of women followed the low-active trajectory. Steps / day increased during spring and decreased during autumn and winter except in the active trajectory group where steps / day did not significantly decrease during autumn. Middle-aged (41–60 years) and older (>60 years) women, and obese or overweight women more likely followed the low-

		months for PA); weekly reporting of PA (median = 104 weeks in the studied sample)						active trajectory class than theactive classes. Women reporting having cardiovascular-related problems less likely followed the active trajectory.
Kivi-niemi et al. (2016)	1) Study the association between lifelong PA and cardiovascular autonomic function in midlife.	Northern Finland Birth Cohort 1966; Finland; longitudinal study; 1980; 34 years; 3	3062 participants (58% females); 14 years	LCA; NR; BIC, interpretability of the classification, conceptual meaningfulness of the model, sizes of the subgroups	SR; LTPA was measured with two questions concerning the frequency of participation in sports outside school hours (at the age of 14) and the frequency of participating to brisk PA / exercise during leisure-time (at the ages of 31 and 46) after which the two answers were combined for the LCA.	Three LTPA trajectories, females: 1) active, 23% 2) semiactive, 51% 3) inactive, 26% Three LTPA trajectories, males: 1) active, 28% 2) semiactive, 43% 3) inactive, 29%	Outcome: cardiovascular autonomic function (vagally mediated heart rate variability and cross-spectral baroreflex sensitivity) at the age of 46 years Covariates: smoking, alcohol consumption, sleep, sitting time, BMI, waist-to-hip ratio, blood pressure, lipid status, glucose status	Higher lifelong PA was independently associated with better cardiovascular autonomic function in midlife in women, while in men this association was mediated by other cardiometabolic and lifestyle factors.
Laddu et al. (2017a)	1) Identify distinct PA trajectories from young adulthood to middle age. 2) Study the association of PA trajectories with the prevalence of coronary artery calcification.	Coronary Artery Risk Development in Young Adults; USA; longitudinal study; 1985–1986; 25 years; 8	3175 (57% females); 18–30 years	GBTM; SAS Proc Traj; BIC, posterior probabilities, qualitative examination	SR; LTPA was measured with several questions (e.g., frequency of participation in vigorous or moderate intensity recreational sports, exercise, home maintenance, and occupational activities during the previous year). A total activity sum-score was expressed in exercise units where a threshold of 300 exercise units was determined as meeting PA guidelines.	Three PA trajectories: 1) three times PA guidelines, 8% 2) meeting PA guidelines, 35% 3) below PA guidelines, 57%	Outcome: presence of coronary artery calcification Covariates: age, race, sex, hypertension, diabetes, smoking status, BMI, education, and hyperlipidemia	White participants following the 'three times PA guideline' trajectory had higher odds of developing subclinical coronary artery disease by middle age compared to the participants following the 'below PA guidelines' trajectory.
Oura et al. (2016)	1) Study the association of LTPA trajectories from adolescence to middle age with vertebral dimensions in adulthood.	Northern Finland Birth Cohort 1966; Finland; longitudinal study; 1980; 34 years; 3	1188 participants (56% females); 14 years	LCA; NR; BIC, interpretability of the classification, conceptual meaningfulness, sizes of the subgroups	SR; LTPA was measured with two questions concerning the frequency of participation in sports outside school hours at the age of 14, and the frequency of participating to brisk PA / exercise during leisure-time at the ages of 31 and 46 years.	Three LTPA trajectories, females: 1) active, 24% 2) moderately active, 46% 3) inactive, 30% Three LTPA trajectories, males: 1) active, 29%	Outcome: vertebral dimensions (lumbar magnetic resonance imaging) at the mean age of 47 years Covariates: height, weight, BMI, SES (educational level), and smoking	A high level of lifetime LTPA was associated with greater vertebral size among women, but only to a small extent. No such association was observed among men.

						2) moderately active, 42% 3) inactive, 29%	status at the age of 46 years	
Rovio et al. (2017)	1) Identify distinct PA trajectories from childhood to midlife. 2) Identify determinants of the PA trajectory class membership.	Young Finns Study; Finland; longitudinal study; 1980; 31 years; 8	3596 at baseline, n=2841 for the PA trajectories (51% females); 9–18 years	GBTM; SAS Proc Traj; BIC, average posterior probabilities (>0.7)	SR; LTPA was measured with several questions (e.g., frequency and intensity of PA, participation in organized PA, participation in sport competitions, habitual way of spending leisure-time, frequency of vigorous PA, hours spent on vigorous PA, and average duration of PA session) between ages 9 and 49 years. LTPA index was calculated based on these questions.	Five trajectories of LTPA: 1) persistently active, 7% 2) decreasingly active, 14% 3) increasingly active, 14% 4) persistently low active, 51% 5) persistently inactive, 15%	Determinants: residential status, BMI, parental educational level in childhood, participants' self-reported educational level in adulthood, parental LTPA, participants' childhood academic performance, marital status, number of children, current smoking status, and alcohol drinking frequency	The prevalence of persistently low and inactive participants was high in the studied population. Academic achievement, education, having children, smoking, and alcohol use were the most prevailing determinants for the PA trajectories.
Articles in the oldest group (late middle-aged and older adults)								
Aggio et al. (2018)	1) Identify distinct PA trajectories from midlife to old age. 2) Identify predictors of PA trajectory class membership.	British Regional Heart Study; Great Britain; longitudinal study; 1978–1980; 20 years; 4	7735 adults (100% males), n=4952 for PA trajectories; 40–59 years	GBTM; Stata Traj plugin; BIC, log Bayes factor, the proportion of participants in each class at least 5%, close agreement between the estimated probability of group membership and actual proportion of the sample assigned to the group, posterior probabilities (>0.7), odds of correct classification based on posterior probabilities exceeding 5.	SR; PA level was studied by asking several questions concerning time spent on walking, recreational activities and engagement in sport / exercise. Responses to different type of PA were scored based on the intensity and frequency of the activity. A total PA index was created based on scores on type of PA (six categories).	Three PA trajectories, males: 1) low-decreasing, 25% 2) light stable, 51% 3) moderate-increasing, 24%	Predictors: occupation, marital status, number of children, health conditions, other health problems, BMI, smoking status, alcohol consumption, region of residence, and weekly breakfast cereal consumption Covariates: cardiovascular disease diagnoses and employment status	A quarter of participants had persistently low PA level. The results showed that men who followed moderate increasing PA or light stable PA trajectories had fewer health conditions, had better social background characteristics in midlife and generally engaged in other healthy behaviors than men who followed low decreasing PA trajectory. Leaving employment (meaning usually retirement) and cardiovascular disease - related conditions varied according to trajectory class membership.
Artaud et al. (2016)	1) Identify separate trajectories of PA, smoking, alcohol, and fruit and vegetable consumption. 2) Study the associations between the trajectories and	Whitehall II cohort study; Great-Britain; longitudinal study; 1985–1988; 28 years (19 years for PA); 11 (health behaviors have been	6825 civil servants (71% males), n=10205 for PA trajectories; 35–55 years	GBTM; SAS Proc Traj; BIC, posterior probabilities (≥0.7)	SR; Frequency and duration of PA were categorized into recommended level, inactivity, and intermediate PA.	Four PA trajectories: 1) persistent inactivity, 15% 2) intermediate then inactivity, 36% 3) intermediate then recommended, 23% 4) persistently recommended level, 27%	Outcome: disability over 8 years (mobility, instrumental activities of daily living, and basic activities of daily living) Covariates: sex, age, marital status, SES, disability	Forty-two per cent of the participants followed one unhealthy trajectory, 20% two or three, and 38% none. Higher education, being married or cohabiting, and a better health profile were associated with following fewer unhealthy trajectories. Unhealthy trajectories of PA, smoking, and alcohol consumption from midlife to old age were independently associated with increased risk of subsequent disability

	disability at older age.	assessed 5 times in years 1985–2004)					assessment, depressive symptoms, BMI, cognition, bone fractures, chronic conditions, psychotropic drug use, cardiovascular disease and its risk factors	with this risk increasing progressively with the number of unhealthy trajectories.
Gabriel et al. (2017)	1) Study the change in PA during midlife. 2) Study the association of PA trajectories with physical function in later life.	Study of Women's Health Across the Nation; USA; longitudinal study; 1996–1997; 20 years; baseline and 15 follow-ups (PA data were collected at baseline and at 6 follow-ups)	1771 adults (100% females); 42–52 years	LCGA; SAS Proc Traj; BIC, scientific plausibility, highest prior probability	SR; A sports index comprising of the intensity, frequency and duration of two most frequent sports, at least in moderate intensity level (≥ 3 METs), and sport and exercise activities over the previous 12 months	Five trajectories of PA, females: 1) highest, 14% 2) middle, 24% 3) decreasing, 22% 4) increasing, 13% 5) lowest, 26%	Outcome: physical function (40 foot walk, 4 meter walk, repeated chair stands, and grip strength) Covariates: age, ethnicity, site, sociodemographic factors, other health behaviors (e.g., smoking status), BMI, self-rated health status, bodily pain, physical difficulties, menopausal status, hormone use, presence of depressive symptoms, and self-reported comorbidities	The highest PA trajectory group had the most favorable physical functioning outcomes (all $p < 0.001$) when compared to other PA groups. Statistically significant differences in the physical functioning were observed when all other trajectory groups were compared to the lowest or increasing PA trajectory group. Characteristics associated with the lowest PA trajectory group were being Hispanic and Black, being single or never married, having fair or poor overall health status, being obese, having income < $35,000 per year, being current cigarette smoker, having severe or very severe bodily pain, having reported physical difficulties and having osteoarthritis.
Hsu et al. (2013)	1) Identify separate trajectories of regular exercise, smoking, drinking alcohol, and having general health checkups for elderly men and women. 2) Identify multiple trajectories of four health-related behaviors. 3) Describe the longitudinal trajectories of multiple health behaviors and identify factors	Taiwan Longitudinal Survey on Aging; Taiwan; longitudinal study; 1996; 11 years; 4	5880 older people (99% community -dwelling), n=4800 for trajectories (47% females); ≥50 years	GBTM and joint trajectory model; SAS Proc Traj; BIC, parsimony principle	SR; Getting regular exercise was defined as exercising for at least 30 minutes three times per week.	Four trajectories of regular exercise, females: 1) none or little, 49 % 2) decreasing exercisers, 17% 3) increasing exercisers, 19% 4) regular exercisers, 14% Four trajectories of regular exercise, males: 1) non-exercisers, 44% 2) decreasing exercisers, 11% 3) increasing exercisers, 23% 4) regular exercisers, 21 %	Predictors: age, number of years of education, marital status, self-related health, depressive symptoms, social support, social participation, and economic satisfaction at baseline	Five distinct trajectory groups of multiple health-related behaviors were identified for men (smoking, inactive, healthy lifestyle, smoking and drinking, and quitting) and three for women (smoking and drinking, inactive and healthy lifestyle). Age, education, self-rated health, depressive symptoms, and economic satisfaction at baseline associated with the health behavior trajectories. Studying multiple longitudinal trajectories instead of only single behavior trajectories can give new insight concerning the clustering of health behaviors across time.

	related to the different trajectory groups.							
Laddu et al. (2017b)	1) Identify distinct trajectories of PA and body composition in older men. 2) Study the association of PA trajectories with body composition trajectories over time.	Osteoporotic Fractures in Men Study; USA; longitudinal study; 2000–2002; 7 years; 3	5964 adults (100% males); ≥64 years (mean = 74 years)	GBTM; Stata Traj; determining the maximum number of trajectory groups a priori, BIC, posterior probabilities, only specific groups comprised of at least 1% of the analytic cohort were included	SR; PA was measured with the Physical Activity Scale for the Elderly which measures total, occupational, household and LTPA over the previous seven days. A total PA score was summed for each participant.	Three PA trajectories, males: 1) high-declining, 7% 2) moderate-declining, 50% 3) low-declining, 43%	Outcome: body composition	A decline in PA was observed in all PA trajectories, with the greatest decline in the high-declining PA trajectory group. Men in the high-declining group reported higher PA levels throughout the study period when compared to other two PA groups. Among high-declining and low-declining PA trajectory groups total body weight and lean mass significantly declined while fat mass stayed relatively unchanged. Fat mass increased in the moderate-declining PA trajectory group.
Nguyen et al. (2013)	1) Identify recreational PA trajectories among postmenopausal women 2) Examine whether women following different PA trajectories engage in different types of PA. 3) Study baseline sociodemographic characteristics, lifestyle behaviors, health, and psychosocial status as predictors of PA trajectory membership.	Women's Health Initiative Observation Study; USA; prospective, multicenter clinical trial and observational study; 1993–1998; 8 years; 7	92629 adults (100% females, 83% White); 50–79 years women were divided into three age-groups at baseline: 50–59 years (32%), 60–69 years (44%) and >70 years (24%).	Latent profile analyses, latent growth curve modeling; Mplus; BIC, AIC, class interpretability, class prevalence, entropy (higher value close to 1 representing a better classification)	SR; Recreational PA was defined as energy expenditure expressed as MET-hours / week.	Three recreational PA trajectories across the three age groups (50–59 / 60–69 / >70 years), females: 1) minimally active, ranging between 70%–74% in each age group 2) moderately active, 23%–25% 3) highly active, 4%–5%	Predictors: age, ethnicity, marital status, living situation, education, income, employment status, caregiving responsibilities, current residence, smoking, dietary patterns, alcohol intake, hormone use, previous participation in vigorous exercise, height, weight, health-related quality of life, history of falls, hip fractures, hospitalizations, chronic medical illnesses, depressive symptoms, history of depression, and social support	Nearly 75% of the participants were following the minimally active trajectory. Sociodemographic characteristics (e.g., ethnicity, income, and education), some health status indicators (e.g., BMI), and past vigorous PA were predictive of PA trajectory class membership.
Pan et al. (2015)	1) Identify PA trajectories among Taiwanese older adults. 2) Identify the related factors of the different trajectories.	Taiwan Longitudinal Study for Aging; Taiwan; follow-up study; 1996; 11 years; 4	4018 older adults (49% females); 50–96 years (mean = 65 years)	GBTM; SAS Proc Traj; BIC, posterior probabilities (≥0.7)	SR; Frequency and duration of sports and exercise. Being physically active was determined as performing sports or exercises at least three times in a week, and at least for 30 minutes each time.	Four PA trajectories: 1) inactive, 48% 2) decreasing, 12% 3) increasing, 23% 4) active, 17%	Covariates: sex, years of education, age, ethnicity, depressive symptoms, physical functional limitations, self-rated health, marital status, economic satisfaction, residential area, and working status	Heterogeneity of PA was found among Taiwanese older adults. Nearly half of the participants were following the inactive trajectory. Older age and higher educational level were positively associated with being active. Those participants having jobs, depressive symptoms, and several physical functional limitations were less likely to be physically active in the decreasing, increasing, and active patterns.

Xue et al. (2012)	1) Identify PA trajectories among older women. 2) Assess the associations of PA trajectories with all-cause mortality. 3) Identify predictors of change in PA.	Women's Health and Aging Study II; USA; prospective cohort study; 1994; 12 years; 7	433 adults (100% females); 70–79 years	Joint latent class and survival mixture model; Mplus, and Stata; Lo-Mendell-Rubin adjusted likelihood ratio test, scientific plausibility, meaningfulness of the trajectory patterns, person-specific probabilities (higher value representing a better classification)	SR; The frequency and duration of participation into different exercise, and lifestyle and outdoor activities. Activity level was classified into three categories (inactive, moderately active and very active) based on kcal / kg / day.	Four PA trajectories, females: 1) always active, 17% 2) fast declining, 19% 3) stable moderate, 32% 4) always sedentary, 32%	Predictors: BMI, number of chronic diseases, having depressive symptoms, mobility disability, living alone, self-efficacy, energy level, self-reported health, and smoking status Outcome: all-cause mortality Covariates: baseline age, race, and educational level	Maintaining an active or moderately active lifestyle was associated with the lowest mortality rate. A curvilinear relationship between the lower levels of PA and higher mortality risk was observed indicating that the greatest gain of increasing PA would be among those women with lowest PA levels. Depressive symptoms, coronary artery disease, mobility disability, obesity, chronic obstructive pulmonary disease, low self-efficacy, and low energy were associated with sedentary behavior and with a fast decline in activity.

NR not reported; *NA* not applicable; *PA* physical activity; *SP* sport participation; *MVPA* moderate to vigorous intensity physical activity; *LTPA* leisure-time physical activity; *MET* metabolic equivalent; *SR* self-report; *PR* parent-report; *OBM* objectively measured; *GBTM* group-based trajectory modeling; *GGMM* general growth mixture modeling; *LCA* latent class analysis; *LCGA* latent class growth analysis; *BLRT* bootstrap likelihood ratio test; *BIC* Bayesian information criterion; *ABIC* adjusted Bayesian information criterion; *AIC* Akaike's information criterion; *BMI* body mass index; *SES* socioeconomic status

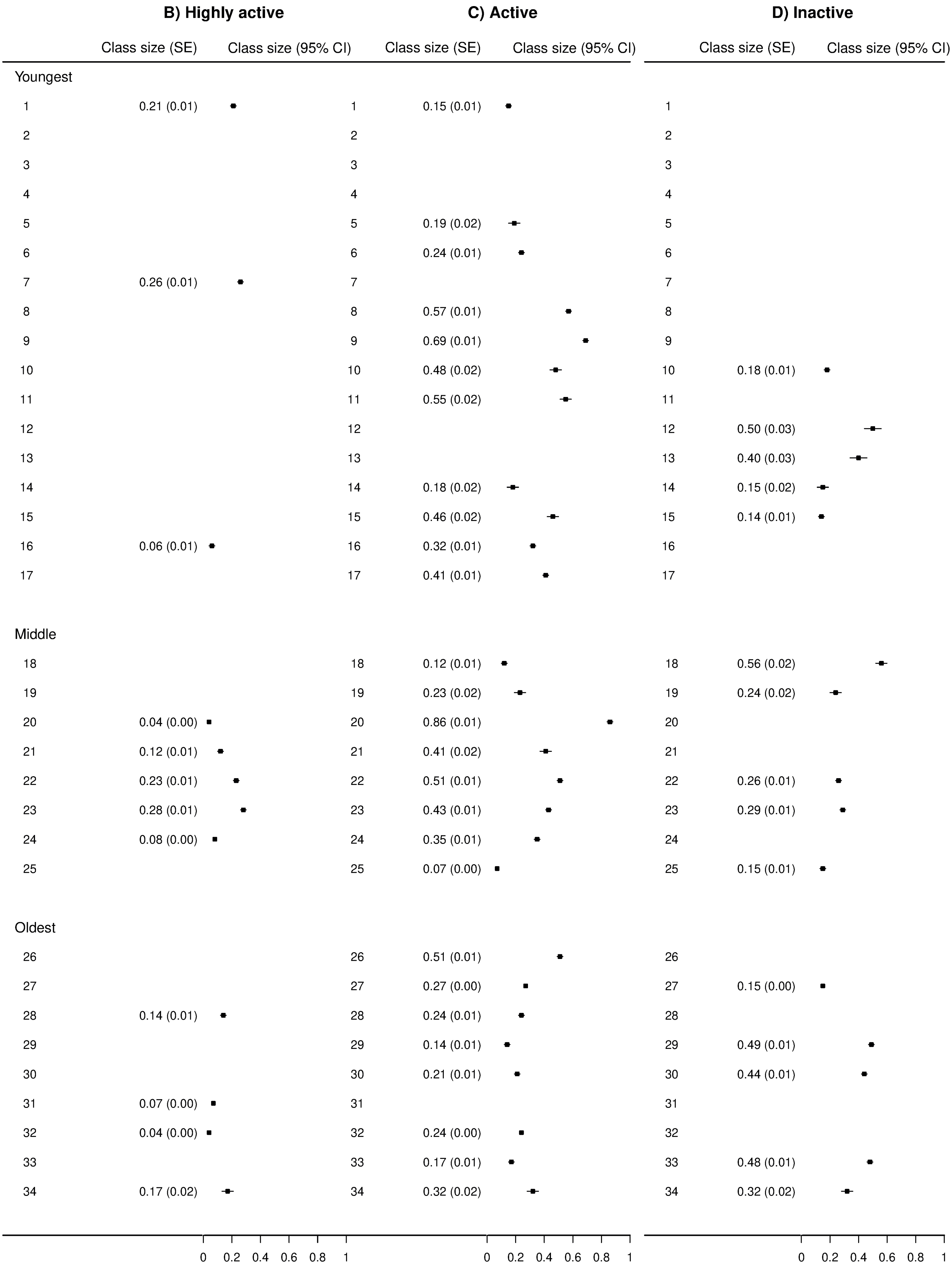
**Entropy* = Average classification probability

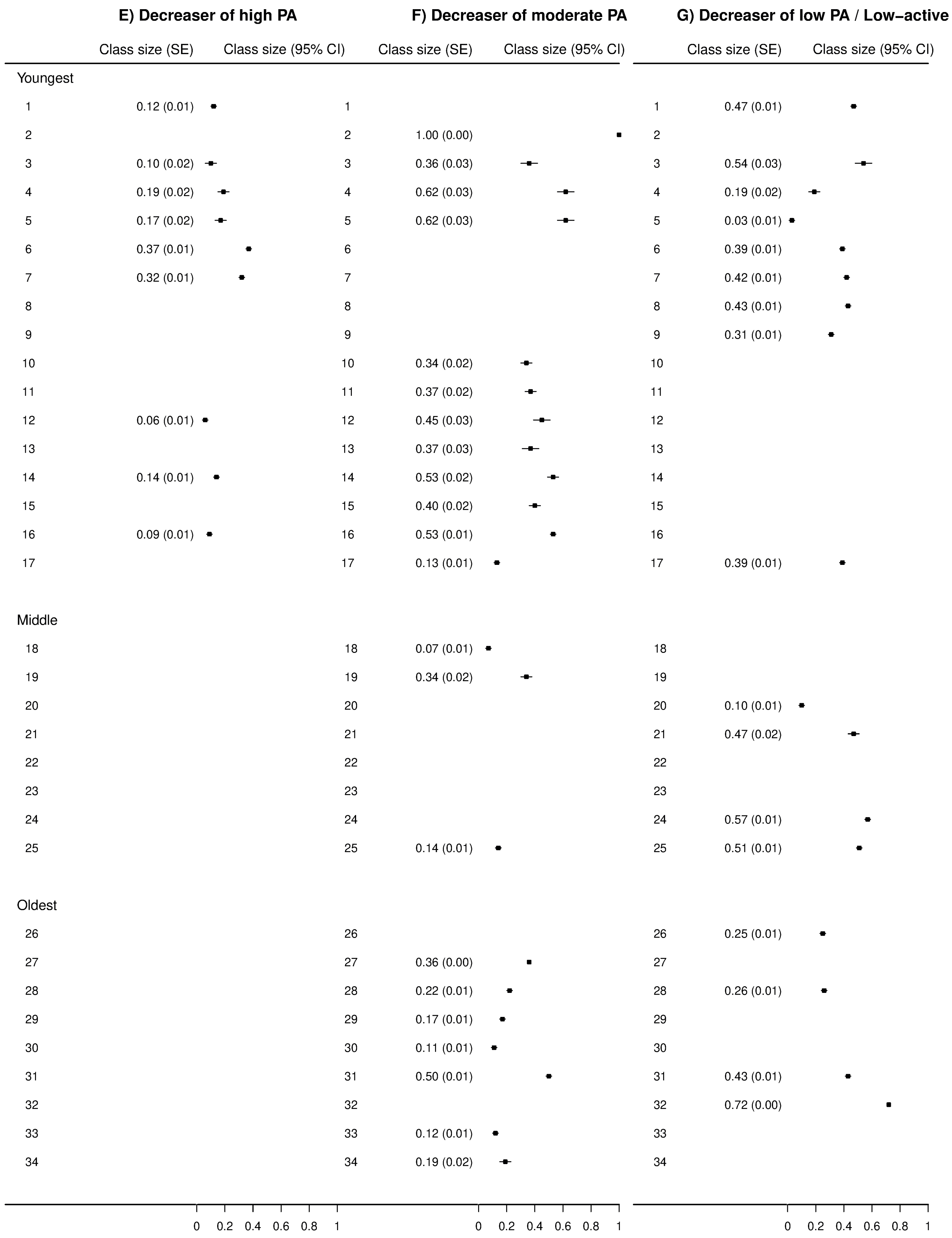
Additional file 4: Forest plot. Physical activity trajectories divided into categories by age group

A) From increaser to decreaser / Increaser **

	N	Measure	Method	Class size (SE)
Youngest group				
1 Audrain−McGovern, 2012	1,429	MVPA	SR	0.05 (0.01)
2 Farooq 2017: Females	283	Total PA volume	OBM	
3 Farooq 2017: Males	262	Total PA volume	OBM	
4 Farooq 2017: Females	283	MVPA	OBM	
5 Farooq 2017: Males	262	MVPA	OBM	
6 Findlay, 2009: Females	4,497	Organized PA	PR + SR	
7 Findlay, 2009: Males	4,320	Organized PA	PR + SR	
8 Findlay, 2010: Females	4,489	Unorganized PA	PR + SR	
9 Findlay, 2010: Males	4,489	Unorganized PA	PR + SR	
10 Howie, 2016: Females	823	Organized SP	PR	
11 Howie, 2016: Males	856	Organized SP	PR	0.08 (0.01)
12 Janz, 2014: Females	265	MVPA	OBM	
13 Janz, 2014: Males	265	MVPA	OBM	0.23 (0.03)
14 Kwon, 2015a*	537	MVPA	OBM	
15 Kwon, 2015a*	537	SP	SR	
16 Kwon, Lee, Carnethon, 2015: Females	2,155	PA	SR	
17 Rodriguez, 2004	1,098	Team participation	SR	0.07 (0.01)
Middle group				
18 Barnett, 2008	884	LTPA	SR	0.25 (0.01)
19 Dishman, 2010	497	MVPA	SR	0.19 (0.02)
20 Kaseva, 2016	3,564	LTPA	SR	
21 Kim, 2016: Females	669	PA	OBM	
22 Kiviniemi*, 2016: Females	1,776	LTPA	SR	
23 Kiviniemi*, 2016: Males	1,286	LTPA	SR	
24 Laddu, 2017a	3,175	LTPA	SR	
25 Rovio, 2017	2,841	LTPA	SR	0.14 (0.01)
Oldest group				
26 Aggio, 2018: Males	4,952	PA	SR	0.24 (0.01)
27 Artaud, 2016	10,205	PA	SR	0.23 (0.00)
28 Gabriel, 2017: Females	1,771	Sport and exercise	SR	0.13 (0.01)
29 Hsu, 2013: Females	2,256	Regular exercise	SR	0.19 (0.01)
30 Hsu, 2013: Males	2,544	Regular exercise	SR	0.23 (0.01)
31 Laddu, 2017b: Males	5,964	PA	SR	
32 Nguyen, 2013: Females	92,629	PA	SR	
33 Pan, 2015	4,018	PA	SR	0.23 (0.01)
34 Xue, 2012: Females	433	PA	SR	

Class size (95% CI)


B) Highly active
C) Active
D) Inactive
Class size (SE) Class size (95% CI)
Class size (SE) Class size (95% CI)
Class size (SE) Class size (95% CI)
Youngest
1 0.21 (0.01) 1 0.15 (0.01) 1
2 2 2
3 3 3
4 4 4
5 5 0.19 (0.02) 5
6 6 0.24 (0.01) 6
7 0.26 (0.01) 7 7
8 8 0.57 (0.01) 8
9 9 0.69 (0.01) 9
10 10 0.48 (0.02) 10 0.18 (0.01)
11 11 0.55 (0.02) 11
12 12 12 0.50 (0.03)
13 13 13 0.40 (0.03)
14 14 0.18 (0.02) 14 0.15 (0.02)
15 15 0.46 (0.02) 15 0.14 (0.01)
16 0.06 (0.01) 16 0.32 (0.01) 16
17 17 0.41 (0.01) 17
Middle
18 18 0.12 (0.01) 18 0.56 (0.02)
19 19 0.23 (0.02) 19 0.24 (0.02)
20 0.04 (0.00) 20 0.86 (0.01) 20
21 0.12 (0.01) 21 0.41 (0.02) 21
22 0.23 (0.01) 22 0.51 (0.01) 22 0.26 (0.01)
23 0.28 (0.01) 23 0.43 (0.01) 23 0.29 (0.01)
24 0.08 (0.00) 24 0.35 (0.01) 24
25 25 0.07 (0.00) 25 0.15 (0.01)
Oldest
26 26 0.51 (0.01) 26
27 27 0.27 (0.00) 27 0.15 (0.00)
28 0.14 (0.01) 28 0.24 (0.01) 28
29 29 0.14 (0.01) 29 0.49 (0.01)
30 30 0.21 (0.01) 30 0.44 (0.01)
31 0.07 (0.00) 31 31
32 0.04 (0.00) 32 0.24 (0.00) 32
33 33 0.17 (0.01) 33 0.48 (0.01)
34 0.17 (0.02) 34 0.32 (0.02) 34 0.32 (0.02)
0 0.2 0.4 0.6 0.8 1
0 0.2 0.4 0.6 0.8 1
0 0.2 0.4 0.6 0.8 1


E) Decreaser of high PA
Class size (SE)
Class size (95% CI)
Youngest
1 0.12 (0.01)
2
3 0.10 (0.02)
4 0.19 (0.02)
5 0.17 (0.02)
6 0.37 (0.01)
7 0.32 (0.01)
8
9
10
11
12 0.06 (0.01)
13
14 0.14 (0.01)
15
16 0.09 (0.01)
17
Middle
18
19
20
21
22
23
24
25
Oldest
26
27
28
29
30
31
32
33
34
0
0.2
0.4
0.6
0.8
1
F) Decreaser of moderate PA
Class size (SE)
Class size (95% CI)
1
2 1.00 (0.00)
3 0.36 (0.03)
4 0.62 (0.03)
5 0.62 (0.03)
6
7
8
9
10 0.34 (0.02)
11 0.37 (0.02)
12 0.45 (0.03)
13 0.37 (0.03)
14 0.53 (0.02)
15 0.40 (0.02)
16 0.53 (0.01)
17 0.13 (0.01)
18 0.07 (0.01)
19 0.34 (0.02)
20
21
22
23
24
25 0.14 (0.01)
26
27 0.36 (0.00)
28 0.22 (0.01)
29 0.17 (0.01)
30 0.11 (0.01)
31 0.50 (0.01)
32
33 0.12 (0.01)
34 0.19 (0.02)
0
0.2
0.4
0.6
0.8
1
G) Decreaser of low PA / Low−active
Class size (SE)
Class size (95% CI)
1 0.47 (0.01)
2
3 0.54 (0.03)
4 0.19 (0.02)
5 0.03 (0.01)
6 0.39 (0.01)
7 0.42 (0.01)
8 0.43 (0.01)
9 0.31 (0.01)
10
11
12
13
14
15
16
17 0.39 (0.01)
18
19
20 0.10 (0.01)
21 0.47 (0.02)
22
23
24 0.57 (0.01)
25 0.51 (0.01)
26 0.25 (0.01)
27
28 0.26 (0.01)
29
30
31 0.43 (0.01)
32 0.72 (0.00)
33
34
0
0.2
0.4
0.6
0.8
1

Abbreviations: N = sample size of the study population; SE = standard error; CI = confidence interval; PA = physical activity; MVPA = moderate to vigorous intensity physical activity; LTPA = leisure-time physical activity; SP = sport participation; OBM = objectively measured; SR = self-reported; PR = parent-reported.

*These exact same trajectories were reported in other study / other studies as well. The duplicates were omitted from the figure.

**The From increaser to decreaser category applies to the youngest group while the Increaser category applies to the middle and the oldest group.

Additional file 5: Table S4. Quality assessment checklist and quality scores of the included studies.

Author (publication year)	1. Was the research question or objective in this paper clearly stated?	2. Was the study population specified and defined?	3. Was the participation rate of eligible persons at least 50% at baseline?	4. Was loss to follow-up after baseline defined?	5. Were inclusion and exclusion criteria for the selected subjects defined?	6. Were the potential covariates, confounders, determinants and / or predictors defined?	7. Were the PA[a] measures clearly defined, and implemented consistently across all study participants?	8. Was the validity and / or reliability of the PA measures reported?	9. Were the PA measures assessed at least three times (i.e., the minimum number of measurement points needed when identifying trajectories)?	10. Was PA objectively measured?	11. Was more than one statistical fit measure taken under consideration when deciding the final number of trajectory classes and was at least one of the used fit measures BIC or ABIC?	12. Were the values of the model fit measures (e.g., BIC, ABIC or AIC) concerning the final solution reported?	13. Were posterior probability values and / or entropy values of the final solution reported or their cut-off values defined?	14. Was a plot of the final solution with the estimated mean trajectories provided?	15. Were the total number of fitted models clearly reported?	16. Were the values of the model fit measures of all the fitted models clearly reported?	**Sum quality score[b] (range 0-16)**	**Quality of the study[c]**
	Questions (1-9) modified from the Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies									Questions (11-16) modified from the Guidelines for Reporting on Latent Trajectory Studies								
YOUNGEST GROUP:																		
Audrain-McGovern et al. (2012)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	15	good
Farooq et al. (2017)	Yes	Yes	Yes	Yes	Yes	NA	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No	No	11	fair
Findlay, Garner & Cohen (2009)	Yes	Yes	CA	CA	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes	No	No	9	fair

Findlay, Garner & Cohen (2010)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	No	No	12	good
Howie et al. (2016)	Yes	Yes	CA	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	14	good
Janz et al. (2014)	Yes	Yes	CA	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No	No	11	fair
Kwon, Lee & Carnethon (2015)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	15	good
Kwon et al. (2015a)	Yes	Yes	CA	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	15	good
Kwon et al. (2015b)	Yes	Yes	CA	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	15	good
Kwon et al. (2016)	Yes	Yes	CA	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	15	good
Rodriguez & Audrain-McGovern (2004)	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	13	good
MIDDLE GROUP:																		
Barnett et al. (2008)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	No	No	12	good
Dishman et al. (2010)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	No	No	11	fair
Kaseva et al. (2016)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	14	good
Kim et al. (2016)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	15	good
Kiviniemi et al. (2016)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	No	No	NA	Yes	No	9	fair
Laddu et al. (2017a)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	No	No	12	good
Oura et al. (2016)	Yes	Yes	Yes[d]	Yes	Yes	Yes	Yes	No	Yes	No	No	No	No	NA	Yes	No	9	fair
Rovio et al. (2017)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	No	13	good
OLDEST GROUP:																		
Aggio et al. (2018)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	15	good
Artaud et al. (2016)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	No	Yes	Yes	No	No	11	fair

Gabriel et al. (2017)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes	No	No	11	fair
Hsu et al. (2013)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes	No	Yes	No	No	10	fair
Laddu et al. (2017b)	Yes	Yes	Yes	Yes	Yes	NA	Yes	Yes	Yes	No	Yes	No	No	Yes	No	No	10	fair
Nguyen et al. (2013)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	15	good
Pan et al. (2015)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	14	good
Xue et al. (2012)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	Yes	No	No	10	fair

PA physical activity; *BIC* Bayesian information criterion; *ABIC* adjusted Bayesian information criterion; *NA* not applicable; *CA* can't answer

[a]PA includes also sport participation and exercise variables.

[b]1 when the criterion was applicable to the analyzed study (1 = yes); 0 when the criterion was not fulfilled, not applicable, or could not be answered based on the information provided by the study (0 = no).

[c]Poor (score ranging from 0 to 5); fair (score ranging from 6 to 11); good (score ranging from 12 to 16).

[d]the participation rate was less than 50% from the original sample but it was 77% of those who had undergone lumbar magnetic resonance imaging.

II

ASSOCIATIONS BETWEEN TRAJECTORIES OF LEISURE-TIME PHYSICAL ACTIVITY AND TELEVISION VIEWING TIME ACROSS ADULTHOOD: THE CARDIOVASCULAR RISK IN YOUNG FINNS STUDY

by

Yang, X., Lounassalo, I., Kankaanpää, A., Hirvensalo, M., Rovio, S., Tolvanen, A., Biddle, S. J. H., Helajärvi, H., Palomäki, S. H., Salin, K., Hutri-Kähönen, N., Raitakari, O. T., & Tammelin T. H. (2019)

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Associations Between Trajectories of Leisure-Time Physical Activity and Television Viewing Time Across Adulthood: The Cardiovascular Risk in Young Finns Study

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ABSTRACT

Background: The purpose of this study was to examine trajectories of leisure-time physical activity (LTPA) and television viewing (TV) time and their associations in adults over 10 years. **Methods**: The sample comprised 2934 participants (men, 46.0%) aged 24–39 years in 2001 and they were followed up for 10 years. LTPA and TV-time were assessed using self-report questionnaires in 2001, 2007 and 2011. Longitudinal LTPA and TV-time trajectories and their interactions were analyzed with mixture modeling. **Results**: Three LTPA (persistently highly active, 15.8%; persistently moderately active, 60.8%; and persistently low-active, 23.5%) and four TV-time (consistently low, 38.6%; consistently moderate, 48.2%; consistently high, 11.7%; and consistently very high, 1.5%) trajectory classes were identified. Persistently highly active women had a lower probability of consistently high TV-time than persistently low-active women (*P* = .022), while men who were persistently highly active had a higher probability of consistently moderate TV-time and a lower probability of consistently low TV-time than their persistently low-active counterparts (*P* = .032 and *P* = .007, respectively). **Conclusions:** Maintaining high LTPA levels were accompanied by less television viewing over time in women, but not in men. The associations were partially explained by education, body mass index and smoking.

Keywords: exercise, sedentary behavior, screen time, epidemiology

In recent decades, lifestyle has become more sedentary both during working hours and leisure time, especially in high income countries.[1] Sedentary behavior is commonly defined as any waking behavior characterized by an energy expenditure ≤1.5 metabolic equivalents while in a sitting, lying or reclining posture,[2] and it should be distinguished from 'physical inactivity'.[3] Of various sedentary behaviors, television viewing (TV) time still remains the most prevalent in Finland despite the proliferation of other electronic devices.[4] Increased TV-time has been found to be associated with more adverse health and behavioral outcomes than other domains of sedentary behavior (e.g., using a computer, sitting during transportation or sitting at work),[5,6] and it may even lead to premature deaths during adulthood.[7] On the other hand, evidence shows that regular leisure-time physical activity (LTPA) has long-term health benefits and contributes substantially to reduction of all-cause mortality.[8]

Although LTPA is one key intervention to reduce TV-time, the association between LTPA and TV-time in adults remains to be clarified. According to a recent systematic review,[9] only three observational studies (two cross-sectional[10,11], one longitudinal study[12]) report a small or moderate inverse association between the two variables. The review concluded that sedentary behavior does not displace moderate to vigorous physical activity (MVPA) but more likely replaces light intensity physical activity when using objective monitoring devices.[9] Regarding associations between physical activity and TV-time trajectories, only two longitudinal studies have explored such an association in youth.[13,14] In both of these studies, participants who maintained higher MVPA levels decreased their TV-time. Thus, the developmental pathways of high MVPA and low TV-time could be related. However, there remains a lack of longitudinal research exploring the linkages between LTPA and TV-time trajectories in adulthood. The strength of the trajectory modeling is that rather than assuming the existence of distinct subgroups (i.e. trajectories) in a population, it identifies them based on the population data.[15]

The aim of this study was threefold: 1) to describe developmental trajectory subgroups of both LTPA and TV-time from young adulthood to early midlife over a 10-year follow-up period, 2) to identify the linkages between LTPA and TV-time trajectory classes, and 3) to examine gender differences in such associations with taking into account age, education, body mass index (BMI), and smoking.

Methods

Participants

The Cardiovascular Risk in Young Finns Study (YFS) is an ongoing longitudinal population-based study consisting of six cohorts born in 1962, 1965, 1968, 1971, 1974 and 1977. The sample of healthy children and adolescents, aged 3, 6, 9, 12, 15, and 18 years, were randomly selected in 1980 from the five Finnish university cities with medical schools (Helsinki, Kuopio, Oulu, Tampere and Turku) and their surrounding communities (*N* = 3596, 83.0% of those who were first invited). The representativeness of study participants has been tested in 2001 by comparing their baseline (1980) characteristics to subjects lost to follow-up.[16] The results showed participants to be older and more often women than subjects lost to follow-up. However, no significant differences were observed in LTPA or TV-time between participants and dropouts.[17,18] The detailed description of the YFS, reasons for non-participation at follow-ups, and the characteristics of the participants have been reported elsewhere.[16]

For the present study, we chose 2001 as the baseline because that was the year when the self-reported TV-time was collected for the first time from all six cohorts. The participants were ages 24–39 years in 2001, and hence, 34-49 years in 2011. Those with missing information on both LTPA and TV-time variables were excluded. Complete data on all variables were available for 2934 healthy adults (men, 46.0%). The study protocol was reviewed and approved by the ethics committees of each of the five participating universities. The informed consent of all subjects was obtained in accordance with the Helsinki Declaration.[16]

Leisure-Time Physical Activity

LTPA in 2001, 2007 and 2011 was measured by a short self-report questionnaire. The questions consisted of items on the intensity of LTPA, frequency of vigorous LTPA, hours spent on vigorous LTPA, average duration of a LTPA session, and participation in organized LTPA. All items were first recoded (1=inactivity or very low activity to 3=regular or vigorous activity) and then summed to create a physical activity index ranging from 5 to 15,[18] with high scores indicative of higher levels of LTPA. Test-retest reliability coefficients of the LTPA values between 2001 and 2007 were >.60.[18] The validity of the LTPA values has been tested by showing a statistically significant correlation with the indicators of exercise capacity (hypothetical maximal workload sustainable for 6 minutes) in a subsample for women (r = .49, P < .001) and men (r = .53, P < .001)[19] and with 7-day pedometer data obtained for total steps (r = .24, P < .001) and aerobic steps (r = .31, P < .001).[20]

Television Viewing Time

Self-reported TV-time in adulthood was measured with a question: "How many hours / minutes on average per day do you spend watching television?".[17,21] Daily TV-time was recorded in minutes in 2001 and in hours in 2007. In 2011, daily TV-time was measured in minutes separately for weekdays and weekend days. A mean daily TV-time was calculated [(5×weekday)+(2×weekend)]/7. To have the same unit of measurement for TV-time, all three measurements of daily TV-time were converted into one-hour increments (hours of daily TV-time) prior to statistical analysis.

Confounders

In 2001, educational attainment was self-reported and measured as completed school years. Body weight was measured with a Seca scale and body height with a Seca anthropometer (Vogel & Halke, Hamburg, Germany). BMI was calculated as weight (kg)/height (m^2). Smoking habits were obtained by a questionnaire, those smoking on a daily basis were deemed as smokers.

Statistical Analysis

Descriptive statistics were calculated using IBM SPSS Statistics for Windows, version 20.0 (IBM Corp. Armonk, NY, USA) and further modeling was performed using Mplus, version 7.0.[22] To identify LTPA and TV-time trajectory subgroups in adulthood, latent profile analyses were conducted. Latent profile analysis is a special case of a wider family of mixture models. The heterogeneous population is considered to consist of subgroups of individuals, but the group membership is unknown. Mixture modeling is a tool to statistically identify these homogeneous subgroups in a data driven way. First, the latent profile analysis was carried out separately for both outcomes. The classification was based on the means of the outcome measures in 2001, 2007 and 2011, and error variances were assumed to be equal across classes. A model with two to six classes was fitted with gender and age covariates. Several fit-indices were used to evaluate the goodness-of-fit of the latent profile analyses with different number of classes: Akaike's information criterion (AIC), Bayesian information criterion (BIC), and sample-size adjusted BIC (ABIC). The model with lower values of information criteria fitted the data better than an alternative model with higher values. Furthermore, the following statistical tests were used to determine the sufficient number of classes: Vuong-Lo-Mendell-Rubin likelihood ratio test (VLMR), Lo-Mendell-Rubin (LMR) adjusted likelihood ratio test and parametric bootstrapped likelihood ratio test (BLRT). The estimated model was compared to the model with one class less, and the low *p*-value of the test indicates that the model with one class less was rejected in favor of the estimated model. The quality of the classification was evaluated using entropy values and the average posterior probabilities for most likely latent class membership (all ranging from 0 to 1 for both measures, value 1 indicating perfect classification). The average posterior probabilities higher than 0.7 were considered acceptable.[22]

Second, interrelationship between the longitudinal patterns of LTPA and TV-time was examined via transition probabilities obtained from multinomial logistic regression analysis (i.e. dual trajectory model).[23] A multinomial logistic regression model was specified between the latent class variables: the latent class variable of TV-time was regressed on the latent class variable of LTPA. Gender was allowed to be associated with both the latent class variables and to moderate the association between LTPA and TV-time.[20] The model was adjusted for potential confounding variables including age, education, BMI, and smoking. The confounders were allowed to be associated with both the latent class variables. The differences in the gender effect on latent class variable of TV-time across the LTPA classes (i.e. interaction of gender and LTPA on TV-time) were tested. The adjusted transition probabilities (i.e., conditional probabilities for TV-time trajectory classes given to LTPA trajectory classes) were calculated separately for men and women using the parameter estimates of the model and setting age, education and BMI to their overall mean and smoker to non-smoker.

Missing data were assumed to be missing at random (MAR). Parameters of the models were estimated by using the full information maximum likelihood (FIML) method with robust standard errors, which enabled to use all the data available. The FIML method produced unbiased parameter estimates under MAR assumption.

Results

Participants (1350 men and 1584 women) having at least one measure of LTPA or TV-time were included in the study. For LTPA, 1431 participants (48.8%) completed all three measurements, 775 (26.4%) completed two, 675 (23.0%) completed one, and 53 (1.8%) did not have any information on LTPA. For TV-time, the corresponding figures were 1566 (53.4%), 727 (24.8%), 636 (21.7%), and 5 (0.2%) participants, respectively. Descriptive characteristics of the study sample are presented in Table 1.

Adjusted models (adjusted for gender and age) with four classes provided the best fit for the LTPA data (Table 2). VLMR and LMR were significant ($P < .001$ for both) for the models with less than five classes. Model-fit of the models for LTPA improved with each step. However, after a four-class solution, some of the average posterior probabilities dropped under acceptable level and, therefore, a four-class solution was considered optimal. Longitudinal LTPA trajectory classes were identified: persistently very highly active (3.8%), persistently highly active (17.5%), persistently moderately active (51.1%) and persistently low-active (27.6%). To avoid small cell frequencies, the three-class solution for LTPA (persistently highly active, 15.8%; persistently moderately active, 60.8%; and persistently low-active, 23.5%) was considered more appropriate than a four-class solution for further analyses.

Model-fit of the adjusted models (adjusted for gender and age) for TV-time improved with each step (Table 2). Because only small additional classes were extracted from the five-class solution forward (class sizes <5%), the four-class solution was considered optimal. Longitudinal TV-time trajectory classes were identified: consistently low TV-time (≤1 h/d, 38.6%), consistently moderate TV-time (2 h/d, 48.2%), consistently high TV-time (≥3 h/d, 11.7%), and consistently very high TV-time (≥5 h/d, 1.5%). The last two categories were combined to form "high" in order to further analyze an interpretable model. Quality of the classification for both LTPA and TV-time was acceptable.

The estimation results of the multinomial logistic regression between latent classes of LTPA and TV-time and moderating effect of gender are shown in Table 3. Participants in both persistently moderately active and highly active classes had a lower probability of consistently high TV-time than those in the persistently low-active class (unstandardized regression coefficient b = -1.14, standard error (*s.e.*) = 0.35, P = .001 and b = -2.35, *s.e.* = 0.84, P = .005, respectively). These associations disappeared between the persistently moderately active and low-active classes (b = -0.60, *s.e.* = 0.37, P = .107), and attenuated between the persistently highly active and low active classes (b = -1.44, *s.e.* = 0.70, P = .040) after additional adjustment for education, BMI and smoking. Gender effects on latent class variable of TV-time differed across the LTPA classes. The gender (male) effect on the consistently high TV-time class was positive within the persistently highly active (b = 1.98, *s.e.* = 0.90, P = .027) and moderately active (b = 0.83, *s.e.* = 0.26, P = .001) classes. The male gender effect on the consistently moderate TV-time was also positive within the persistently highly active class (b = 0.96, *s.e.* = 0.38, P = .012). All associations concerning gender effects disappeared after adjustment for the confounding variables.

The age-adjusted latent transition probabilities between LTPA and TV-time trajectory classes for men and women are illustrated in Figure 1 (A and B). The probability of the consistently high TV-time was lower in persistently high active women than in persistently low-active women (3.9% vs. 22.9%, $P < .001$) (Figure 1B). Among men, a similar tendency was observed but the difference between the classes was only marginally significant (13.0% vs. 21.8%, $P = .055$) (Figure 1A). In addition, the probability of the consistently low TV-time was higher in persistently high active women than in persistently low-active ones (54.4% vs. 32.3%; $P = .006$), while no such difference was observed in men (28.9% vs. 38.8%, $P = .132$).

After additional adjustment for BMI, education and smoking, the associations between the persistently highly active and low-active classes on the consistently high TV-time attenuated in women (9.2% vs. 26.2%, $P = .022$) and disappeared in men (17.0% vs. 19.8%, $P = .571$). Men who were persistently highly active had a higher level of consistently moderate TV-time than those who were persistently low-active (68.4% vs. 51.1%; $P = .032$), while persistently high active men had a lower level of consistently low TV-time than their persistently low-active counterparts (14.2% vs. 29.3%; $P = .007$). No group differences were observed in either consistently moderate TV-time class or consistently low TV-time class in women after additional adjustment for the covariates.

Discussion

The purpose of this study was to identify distinctive, potentially previously unobserved, stable and changing LTPA and TV-time trajectories among Finnish men and women over a period of 10 years, and to investigate how the identified LTPA trajectory classes were related to the TV-time trajectory classes. Three LTPA (persistently highly active, persistently moderately active and persistently low-active) and four TV-time (consistently low, consistently moderate, consistently high, and consistently very high) trajectory classes were identified. We found an inverse association between persistently high LTPA and excessive TV-time in women, but not in men. The differences were partially explained by education, BMI and smoking.

The largest proportion of participants was identified in the persistently moderately active class. Even though, worldwide, physical inactivity is usually more prevalent among women than among men, it is not the case in Finland.[24] The present study supports this observation with the proportion of physically low-active women being lower than physically low-active men. This study did not identify LTPA trajectory classes describing change in the LTPA behavior in adulthood, while previous studies have either found stable LTPA trajectory classes alone[25] or both increasing and decreasing classes in addition to stable classes.[26] The inconsistent findings may be due to a wide range of ages or differences in methodology or measurements.[27]

The consistently moderate TV-time (2 h/d) class was found to be the most prevalent (48.3%), which slightly differs with the previous result showing that the mean daily TV-time in 2015 was 2 hours and 54 minutes per day for Finnish adults aged 25–44 years.[28] Our study found a smaller proportion of adults in the consistently high TV-time class and a larger proportion of adults in the consistently low TV-time class as compared to the previous trajectory studies examining youth only.[13,14,29] One explanation might be that adolescents have more leisure time and fewer responsibilities when compared to adults and therefore they simply spend more time watching television. Previous trajectory studies have identified TV-time change, indicating that the TV behavior has not yet become stable in youth,[13,29] whereas our results suggest that the TV behavior stabilizes to a certain level during adulthood.

Few previous studies have examined the relationship between physical activity and TV-time or sedentary behavior in either men or women. A significant negative association has been found between watching television on a week day and high activity but only in men.[30] In contrast, a few previous studies have reported TV-time to be inversely associated with physical activity among women.[29,31] We found that persistently active women spent less time watching television than persistently active men when compared to their low active counterparts, suggesting that the amount of time women spend watching television competes with time spend on LTPA. Meanwhile, excessive TV-time can coexist for men at low, moderate or high LTPA level. This supports previous findings that sedentary behavior may be independent of MVPA levels,[9] and sedentary behavior and physical activity cannot be seen only as functional opposites.[1,30] In fact, it has been argued that less TV-time can potentially be an important target to promote more active lifestyle for women but not for men due to these different TV-time and LTPA patterns between genders.[31]

One possible explanation for gender differences in the association between LTPA and TV-time may be that women experience clusters of multiple health behaviors more often than men.[32] additionally, men and women have different motivations for participation in LTPA: women have more extrinsic orientation (appearance and physical condition) while men have more intrinsic orientation (mastery and competition).[33] Thus, women's health-consciousness may have an additive effect on their decision-making process in TV-time. Another possible explanation for these differences may be related to the use of leisure time in Finland. Finnish women spend almost an hour more on household work than men on an average day which may lead to those devoting more time to LTPA having less time for watching television. Future research may investigate the motives for TV-time by gender to verify whether health-related reasons or the use of leisure time affect the decision-making.

According to the crude analysis, the findings were as expected: participants who were persistently low-active were more likely to watch more television than those who were persistently moderately active or highly active. However, it is noteworthy that these significant associations mainly disappeared after adjustment for education, BMI and smoking. Findings also indicated that the relationship between LTPA and TV-time for both genders was affected by the confounding variables. Thus, it cannot be excluded that relation between these two variables is caused by a third factor. The causality may be bidirectional:

persons with higher levels of education, lower BMI and non-smoking[34] may be more likely to participate and persist in LTPA, which, in turn, improves resources to reduce the amount of TV-time. On the other hand, it is possible that each of these factors may explain directly or indirectly the reduction of TV-time among women who engage in regular LTPA.

The relationship between TV-time and physical activity is also complicated in the light of their joint effect on health. Evidence shows that MVPA may eliminate the increased risk of death associated with high total sitting time, and attenuates the risk associated with high TV-time.[35] On the other hand, even if adults meet the public health guidelines for physical activity, but also sit for longer periods of time without breaks, their metabolic health may be compromised.[36] In our study, the consistently very high TV-time class accounted for only a small portion of the sample (1.5%), but it is potentially important, since these subjects are characterized by high sitting time. Thus, future studies should seek to replicate the results in health domains.

Strengths and Limitations

To our knowledge, this was the first study to identify TV-time trajectories from young adulthood to middle age and to study their association with LTPA trajectories. Our study has several strengths, including the long follow-up time, large sample size consisting of six age cohorts, and recruitment of subjects throughout Finland. However, a few limitations should be acknowledged. LTPA and TV-time were self-reported and measured only in leisure time and no other sedentary behavior types apart from TV-time were considered. The findings are based on the data in the genetically homogeneous Finnish adults and may not generalize well to other populations, especially those from low-income countries or different ethnic groups.

The statistical analyses used for identifying trajectories have certain strengths. Since the association between LTPA and TV-time was modelled via latent profile analysis, the uncertainty in class membership was taken into account in the analysis. Another strength is that trajectory modeling is data driven, meaning that it is based on objective model fit indicators for identifying the optimal number of latent classes.[37] However, the selection of the number of classes was partly based on interpretability and class sizes because the latent profile analysis with a four-class solution for LTPA could not be conducted due to the small class size of very highly active participants. This led to the selection of the three-class solution for LTPA, which might be a source of bias: the proportion of participants reporting moderate levels of LTPA increased, while participation levels on longitudinal changes in LTPA attenuated or disappeared. This is similar to the situation in TV-time, where only very few participants reported changes in TV-time. Although these results may seem surprising, it is essential that some participants may increase or decrease their LTPA or TV-time 10 years later, but their original behaviors have not changed enough to move towards another trajectory. The limitation of trajectory modeling is that no participant perfectly follows the identified trajectories: each trajectory is a mean description of the behavior of the subgroup where individuals behave as similar as possible within the subgroup while differing from the other subgroups.[38]

Conclusions

Our study represents relatively stable LTPA and TV-time trajectory classes in adults after 10 years of follow-up. The inverse association between persistently high LTPA and excessive TV-time was observed only in women after adjustment for education, BMI and smoking. We suggest that maintaining high level of LTPA is accompanied by less television viewing over time for women but not for men. Future studies should confirm these findings with objective monitoring devices, and the predictors, correlates and health outcomes of the class memberships should be taken into account.

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Legend of Figure 1. Latent transition probabilities of television viewing time trajectories conditional to leisure-time physical activity trajectories adjusted for age for men (A) and women (B).

Table 1. Characteristics of the study sample

Variable	*n*	Mean ± SD/(% of total n)
TV-time in 2001 (hrs/d)	2594	2.0 ± 1.1
TV-time in 2007 (hrs/d)	2224	1.7 ± 1.1
TV-time in 2011 (hrs/d)	1970	1.8 ± 1.2
LTPA in 2001 (score)	2453	8.8 ± 1.9
LTPA in 2007 (score)	2173	8.8 ± 1.8
LTPA in 2011 (score)	1924	9.0 ± 1.8
Age (years) in 2001	2934	31.4 ± 4.9
Gender (%)	2934	
Men	1350	46.0
Women	1584	54.0
Education (years) in 2001	2604	14.5 ± 3.1
Body mass index in 2001	1924	25.0 ± 4.4
Smoking in 2001 (%)	2547	
Smoker	754	29.6
Non-smoker	1793	70.4

TV, television viewing; LTPA, leisure-time physical activity.

Table 2. The estimation results of latent profile analyses of leisure-time physical activity (n = 2886) and television viewing time (n = 2929)

Class	AIC	BIC	ABIC	VLMR	LMR	BLRT	Entropy	Class sizes†‡
LTPA								
2	26072	26143	26105	<.001	<.001	<.001	0.52	58.5%, 41.4%
3	25707	25815	25757	<.001	<.001	<.001	0.62	60.8%, 23.5%, 15.8%
4	25612	25755	25679	<.001	<.001	<.001	0.62	51.1%, 27.6%, 17.5%, 3.8%
5	25570	25749	25654	.026	.028	<.001	0.62	50.8%, 23.4%, 16.9%, 5.4%, 3.5%
6	25547	25761	25647	.324	.331	<.001	0.64	48.5%, 22.7%, 17.5%, 4.7%, 3.4%, 3.1%
TV time								
2	20058	20130	20092	<.001	<.001	<.001	0.78	83.4%, 16.6%
3	19553	19660	19603	.203	.209	<.001	0.70	62.2%, 34.6%, 3.2%
4	19335	19479	19402	.465	.468	<.001	0.67	48.2%, 38.6%, 11.7%, 1.5%
5	19026	19206	19111	.044	.045	<.001	0.84	41.8%, 38.2%, 17.0%, 2.4%, 0.6%
6	18856	19071	18957	.218	.222	<.001	0.85	41.8%, 37.8%, 17.0, 2.4%, 0.6%, 0.4%

†Class counts and proportions for the latent class patterns.

‡Gender and age were included to predict group membership.

AIC, Akaike's information criterion; BIC, Bayesian information criterion; ABIC, Sample-size adjusted Bayesian information criterion; VLMR, Vuong-Lo-Mendell-Rubin likelihood ratio test; LMR, Lo-Mendell-Rubin adjusted LRT test; BLRT, Parametric bootstrapped likelihood ratio test; LTPA, leisure-time physical activity; TV, television viewing.

Table 3. Parameter estimates for the relationship between leisure-time physical activity and television viewing time and modifying effect of gender (*n* = 2934)

	TV-time class (consistently low as reference)					
	Consistently moderate			Consistently high		
Group	*b*	*s.e.*	*p*	*b*	*s.e.*	*p*
LTPA class						
Model 1						
Persistently low-active (as reference)						
Persistently moderately active	-0.22	0.33	.498	-1.14	0.35	.001
Persistently highly active	-0.59	0.39	.135	-2.35	0.84	.005
Model 2						
Persistently low-active (as reference)						
Persistently moderately active	0.07	0.34	.766	-0.60	0.37	.107
Persistently highly active	-0.12	0.40	.834	-1.44	0.70	.040
Gender effect (male) on TV time in distinct LTPA classes						
Model 1						
Persistently low-active	-0.31	0.37	.398	-0.32	0.41	.440
Persistently moderately active	0.31	0.20	.121	0.83	0.26	.001
Persistently highly active	0.96	0.38	.012	1.98	0.90	.027
Model 2						
Persistently low-active	-0.43	0.38	.262	-0.71	0.39	.068
Persistently moderately active	0.10	0.21	.639	0.49	0.26	.060
Persistently highly active	0.70	0.39	.068	1.41	0.74	.058

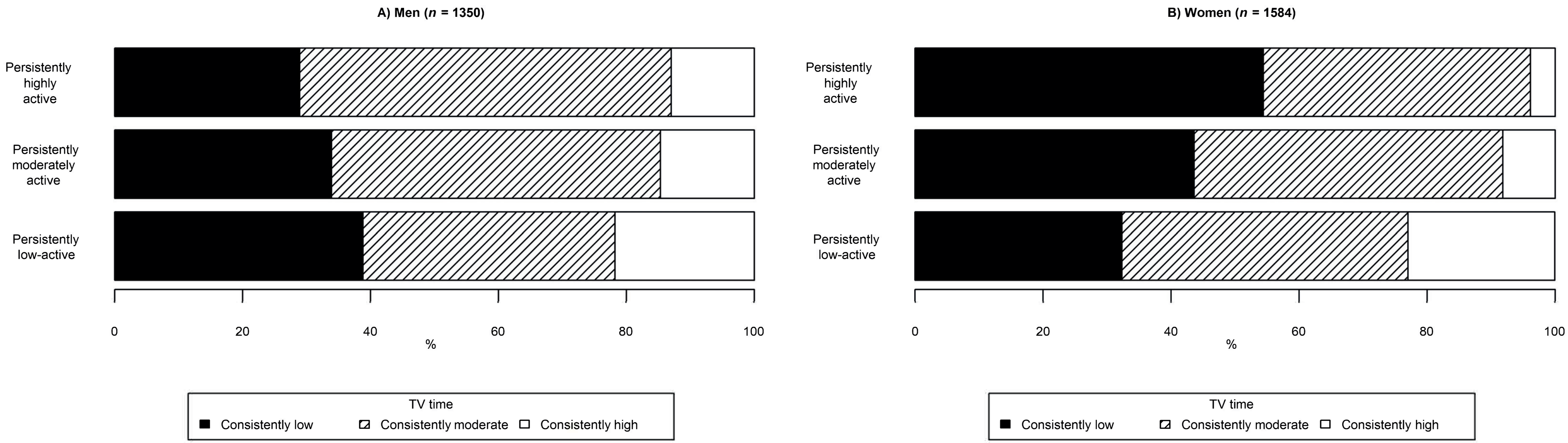
Note: The consistently very high TV-time class that constituted less than 5% of the sample was omitted from the table.

Model 1 was adjusted for age.

Model 2 was additionally adjusted for education, body mass index and smoking.

LTPA, leisure-time physical activity; TV, television viewing; b, regression coefficient; s.e., standard error.

Figure 1: Latent transition probabilities of television viewing time trajectories conditional to leisure-time physical activity trajectories adjusted for age for men (A) and women (B).



III

ASSOCIATIONS OF LEISURE-TIME PHYSICAL ACTIVITY TRAJECTORIES WITH FRUIT AND VEGETABLE CONSUMPTION FROM CHILDHOOD TO ADULTHOOD: THE CARDIOVASCULAR RISK IN YOUNG FINNS STUDY

by

Lounassalo, I., Hirvensalo, M., Kankaanpää, A., Tolvanen, A., Palomäki, S., Salin, K., Fogelholm, M., Yang, X., Pahkala, K., Rovio, S., Hutri-Kähönen, N., Raitakari, O. T., & Tammelin, T. H. (2019)

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Article

Associations of Leisure-Time Physical Activity Trajectories with Fruit and Vegetable Consumption from Childhood to Adulthood: The Cardiovascular Risk in Young Finns Study

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Abstract: A physically active lifestyle and a diet rich in vegetables and fruits have a central role in promoting health. This study examined the associations between leisure-time physical activity (LTPA) trajectories and fruit and vegetable consumption (FVC) from childhood to middle age. The data were drawn from the Cardiovascular Risk in Young Finns Study with six age cohorts. Participants were 9 to 18 years (n = 3536; 51% females) at baseline in 1980 and 33 to 48 years at the last follow-up in 2011. LTPA and FVC were self-reported. LTPA trajectories were identified using latent profile analyses, after which the mean differences in FVC across the trajectories were studied. Active, low-active, decreasingly and increasingly active trajectories were identified for both genders. An additional trajectory describing inactivity was identified for females. Those who were persistently active or increased their LTPA had higher FVC at many ages when compared to their inactive or low-active counterparts ($p < 0.05$). In females prior to age 42 and in males prior to age 24, FVC was higher at many ages in those with decreasing activity than in their inactive or low-active counterparts ($p < 0.05$). The development of LTPA and FVC from childhood to middle age seem to occur in tandem.

Keywords: physical activity; diet; trajectory; longitudinal; childhood; adolescence; adulthood

1. Introduction

In 2010, low fruit intake was ranked the fifth, physical inactivity the tenth, and low vegetable intake the seventeenth global risk factor for disease burden [1]. For example, higher physical activity [2], as well as high fruit, vegetable, and legume intake [3] are associated with a lower risk of cardiovascular diseases and all-cause mortality. Additionally, a physically active lifestyle throughout childhood and adolescence has been found to be a factor preventing obesity in young adulthood [4], while fruit and vegetable intake seems to be inversely, but weakly, associated with weight gain later in life [5]. Since these two behaviors are relevant in regard to health, understanding how they are associated with one another may help in improving public health.

Whereas previous cross-sectional [6] and prospective studies [7] have shown that being physically active is associated with higher consumption of fruits and vegetables, the relationship between the pathways of leisure-time physical activity (LTPA) and fruit and vegetable consumption (FVC) from childhood to adulthood have rarely been researched. Since physical activity [8] and dietary behaviors [9,10] established in childhood and adolescence may track into adulthood, studying the associations between these two behaviors during transition phases from childhood to adolescence and from adolescence to adulthood is important.

A disadvantage of studying the tracking of behaviors is that it does not provide detailed information on subgroups that change their behavior over time. The recent advances in trajectory modelling techniques enable the study of behavioral heterogeneity at different phases of life in a data-driven way [11,12]. For example, in the present instance, it is possible to identify distinctive trajectory classes (i.e., subgroups) of physical activity [13] and FVC [14]. Identifying the key groups of individuals and critical windows during the life course that would be the most receptive to physical activity and dietary promotion would contribute to the enhancement of public health.

The main objective of the present study, with a follow-up lasting over 30 years, was to examine the links between different LTPA trajectories and FVC from childhood to middle age. The study contributes to understanding more profoundly how LTPA develops between and within individuals and how inter- and intra-individual LTPA development is associated with FVC.

2. Materials and Methods

2.1. Study Design and Participants

The Cardiovascular Risk in Young Finns Study (YFS) is an ongoing, longitudinal, population-based study whose participants have been randomly selected from five Finnish university cities with medical schools: Helsinki, Kuopio Oulu, Tampere, and Turku. Urban and rural areas in and around these cities were included. The study comprises six age-cohorts born in 1962, 1965, 1968, 1971, 1974 and 1977. At baseline in 1980, 3596 boys and girls aged 3 to18 years participated in the study (83% of those invited, $n = 4\,320$). Follow-up studies have been conducted in 1983, 1986, 1989, 1992, 2001, 2007 and 2011. Participation rates in the follow-up studies have been satisfactory, ranging from 2060 to 3596, the main reasons for non-participation being lack of interest in the study, the accompanying person being unable to obtain leave from work, child unwilling to participate and fear of clinical examination [15]. Unexpectedly, many participants lost to follow-up earlier in the study have returned.

For the present study, the sample was restricted to participants with at least one measurement of both LTPA and FVC. In addition, since the physical activity data on participants under age nine was parent-reported, we restricted the self-reported LTPA data to ages nine to 48 years ($n = 3536$; 51% females). The representativeness of the study population has been studied by comparing the baseline (1980) characteristics between the sample of the year 2001 and those lost to follow-up [15]. The results showed that participants were older and more often females than non-participants. However, no significant differences in physical activity, body mass index (BMI) or parental years of education were observed between participants and non-participants. A detailed description of the YFS and the study protocol has been published earlier [15].

2.2. Measurements

Leisure-time physical activity. LTPA was assessed eight times between the years 1980 and 2011 (ages 9 to 48) through a self-administered questionnaire. In the years 1980 to 1989, the questionnaire items concerned the frequency and intensity of LTPA, participation in sports-club training, participation in sports competitions, and habitual way of spending leisure-time. In the years 1992 to 2011, the LTPA questionnaire items concerned the frequency and intensity of LTPA, frequency of vigorous LTPA, hours spent on vigorous LTPA, the average duration of an LTPA session, and participation in organized LTPA. All items were first recoded (1 = inactivity or very low activity; 2 = moderately intensive or frequent activity; 3 = frequent or vigorous activity) and then summed to create a physical activity index ranging from 5 to 15 [16,17]. The creation of the original index has been described previously elsewhere [16]. An index value under seven describes inactivity and value of eleven high activity. Six is scored when, for example, participants do not usually experience breathlessness and sweating during physical activity, do not engage in rigorous LTPA, engage in organized physical activity occasionally, and engage in LTPA sessions lasting for 20-40 minutes. Eleven is scored when, for example, participants experience a lot of breathlessness and sweating during physical activity, engage in rigorous LTPA several times and 2-6 hours per week, participate in organized LTPA at least once a week and engage in LTPA sessions lasting for 40-60 minutes.

The criterion validity of the childhood (years 1980-89) and adulthood (year 1992 onward) LTPA index has been tested by studying its correlation with indicators of exercise capacity (hypothetical maximal workload sustainable for 6 minutes) in a subsample (n = 102) of YFS participants. The correlations were significant in childhood (girls: $r = 0.39$; boys: $r = 0.33$) and adulthood (women: $r = 0.49$; men: $r = 0.53$) [16]. In addition, the LTPA index correlated significantly with 7-day pedometer data ($r = 0.24$ for total steps; $r = 0.31$ for aerobic steps) [17], and also with accelerometer data (r = 0.26-0.45) [18].

Fruit and vegetable consumption. FVC was assessed six times using two different self-administered questionnaires. The first questionnaire was used in 1980, 1983, 1986, and 1989 (at ages 9 to 27 years) and consisted of two items: Frequencies of fruit and fruit juice consumption and vegetable consumption separately during the past month. Participants selected one of six response categories: (1) not at all or hardly ever; (2) once or twice a month; (3) once a week; (4) a few times a week; (5) nearly every day; and (6) every day. An FVC index was created by summing the values from the two items. The index ranged from 2 to 12, with high scores indicating high FVC.

In 2007 and 2011 (ages 30 to 48 years), the above questionnaire was replaced with a more comprehensive food frequency questionnaire (FFQ) comprising 131 items on different foods and drinks. The FFQ was developed and validated by the Finnish National Institute for Health and Welfare [19]. Participants reported their monthly, weekly or daily consumption of different food and drink items during the past year. The reported intakes (frequency and portion sizes) of fruits (including fresh and canned fruits and berries) and vegetables (including fresh and canned vegetables, root vegetables, mushrooms, cabbage, pulses and edible bulbs) were first converted into grams per day and then summed to form a variable indicating total daily FVC. Those in the 0.5% of the sample with the highest or lowest scores of the total daily FVC for the years 2007 and 2011 (n = 38) were excluded in order to remove the extreme under- and over-reporters from the further analyses.

Covariates. Participants' BMI, total energy intake, education level, and their own and their mothers' number of years of education were used as covariates. Height was measured with a wall-mounted stadiometer and weight with a digital scale. BMI was calculated as the ratio of weight to the square of height (kg/m^2). Total energy intake was assessed based on the FFQ in 2007 and 2011 [19]. To exclude under- and over-reporters of total energy intake, all those in the 0.5% of the sample with the highest or lowest scores of total energy intake data for the years 2007 and 2011 (n = 38) were excluded from the further analyses. Participants were asked to state education level (primary school, vocational school, high school, and university or equivalent) and their own and their mothers' number of years of education.

2.3. Statistical Analysis

Descriptive statistics were calculated by using IBM SPSS Statistics for Windows, version 24.0 (IBM Corp. Armonk, NY, USA), and expressed as means and standard deviations. Differences in the study variables between males and females were tested by using an independent-samples t-test. Further modelling was performed by using Mplus, version 8.0 [20].

Distinct LTPA trajectory classes from childhood to adulthood have been identified from the YFS data in a previous study for males and females separately by using latent profile analysis, which is a type of finite mixture modelling [21]. The modelling was performed again for the present study as the composition of the sample had changed slightly owing to the requirement that each participant had at least one measurement of LTPA and FVC. The statistical modelling of the LTPA trajectories has been described in a previous paper [21] and is presented in Supplement 1. All analyses were performed separately for males and females owing to differences in LTPA previously observed between the sexes [21]. Missing data were assumed to be missing at random. Model parameters were estimated by using the full information maximum likelihood method with robust standard errors, thus, enabling the use of all the available data.

After identifying the LTPA trajectories, the mean differences in FVC from age 9 to 48 years across the LTPA trajectory classes were studied utilizing the Bolck-Croon-Hagenaars (BCH) approach [22–24]. In the BCH approach, the model estimates for the latent classes (here LTPA) are not affected by the auxiliary variable (FVC), thereby avoiding the class membership changes [24]. First, the BCH weights from the latent profile analysis run with the optimal number of LTPA trajectory classes were saved. BCH weights are group-specific weights computed for each participant during the latent profile model estimation. In the second run, the BCH weights were used as training data, and a multiple group regression model was estimated. FVC was regressed on age-specific covariates within the distinct LTPA trajectory classes, and differences in the regression intercepts (i.e., adjusted means of FVC) across the trajectory classes were studied. When, for example owing to small class size, an error in the computation was reported in Mplus, the residual variances were fixed to a value with the lowest Akaike's Information Criterion, which indicates the best model fit.

The models were adjusted for the participant's BMI at all ages, mother's years of education (at ages 9, 12, 15, 18, and 21), the participant's education level (at ages 24 and 27), the participant's years of education (at ages 30, 33, 36, 39, 42, 45, and 48), and total energy intake (at ages 30, 33, 36, 39, 42, 45, and 48). Standardized values of the covariates were used when adjusting the models.

2.4. Quality Assessment

To enhance reporting quality, the study was conducted according to the Strengthening the Reporting of Observational Studies in Epidemiology–nutritional epidemiology (STROBE-nut) checklist [25] (Supplement 2). The Guidelines for Reporting on Latent Trajectory Studies (GRoLTS) checklist [26] was applied to ensure the quality of the trajectory modelling (Supplement 3).

2.5. Availability of Data and Materials

The datasets analysed during this study are not publicly available for ethical and legal reasons, but are available from the Publication Committee of the YFS on reasonable request. For more information on dataset access, please contact Professor Olli Raitakari, Project Director of the YFS, University of Turku, Finland, olli.raitakari@utu.fi.

2.6. Ethics Approval and Consent to Participate

All subjects gave their informed consent for inclusion before they participated in the study [15]. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the ethics committees of each of the five participating universities (ETMK:68/1801/2017).

3. Results

3.1. Participants and Their Characteristics

The sample size of the present study was 3536 (51% females). All eight LTPA measurements had been completed by 508 participants (14.4%), seven by 579 (16.4%), six by 666 (18.8%), five by 572 (16.2%), four by 453 (12.8%), three by 378 (10.7%), two by 241 (6.8%) and one by 139 (3.9%). For FVC, the corresponding figures were 752 (21.3%), 944 (26.7%), 828 (23.4%), 534 (15.1%), 321 (9.1%), 156 (4.4%) and one (0.03%). Table 1 shows descriptive characteristics and missing data for each study variable at participants' youngest age, nine years of age, and at 45 years. Since the sample size was small at the participant's oldest age, 48 years of age, the age of 45 was chosen to describe the descriptive characteristics of the participants at the end of the study.

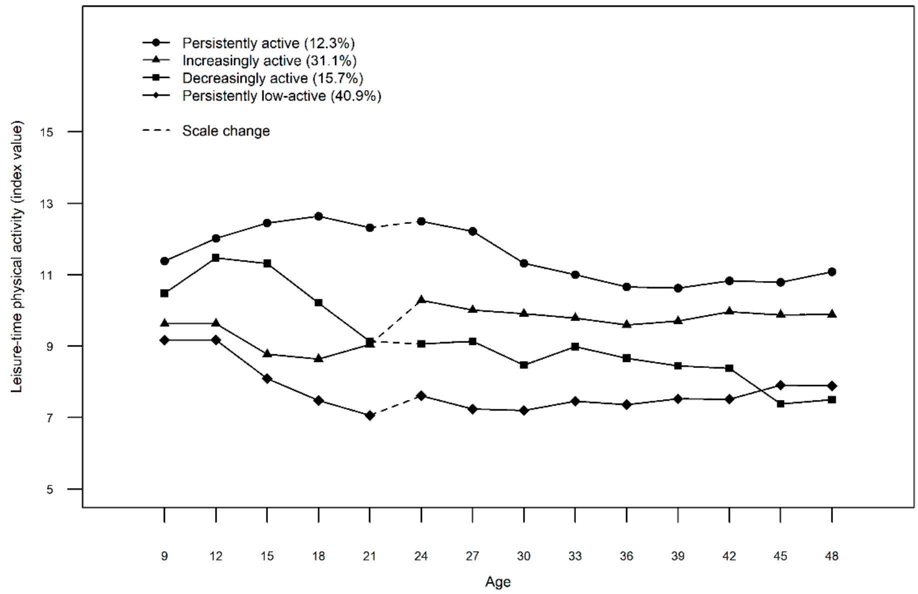
Table 1. Descriptive statistics of the study sample at age 9 and 45.

Descriptive Variable at Age 9 and 45	Males		Females		p [a]
	Mean (sd)	*n* (Missing)	Mean (sd)	*n* (Missing)	
At age 9:					
LTPA (index, range 5–15)	9.9 (1.6)	798 (100)	8.9 (1.4)	807 (101)	< 0.001
FVC frequency (index, range 2–12)	10.2 (1.7)	778 (120)	10.4 (1.5)	803 (105)	0.010
BMI (kg/m^2)	16.7 (2.3)	814 (84)	16.7 (2.3)	831 (77)	0.612
Mothers' education (years)	10.9 (3.3)	798 (100)	10.7 (3.2)	804 (104)	0.315
At age 45:					
LTPA (index value, range 5–15)	8.8 (1.9)	305 (239)	8.9 (1.7)	380 (215)	0.405
FVC (grams per day)	390 (206)	297 (247)	494 (214)	367 (228)	< 0.001
Total energy intake (kcal/day)	2629 (799)	297 (247)	2139 (604)	367 (228)	< 0.001
BMI (kg/m^2)	27.3 (4.2)	318 (226)	26.3 (5.6)	391 (204)	0.004
Education (years)	14.5 (3.6)	315 (229)	15.4 (3.4)	388 (207)	0.001

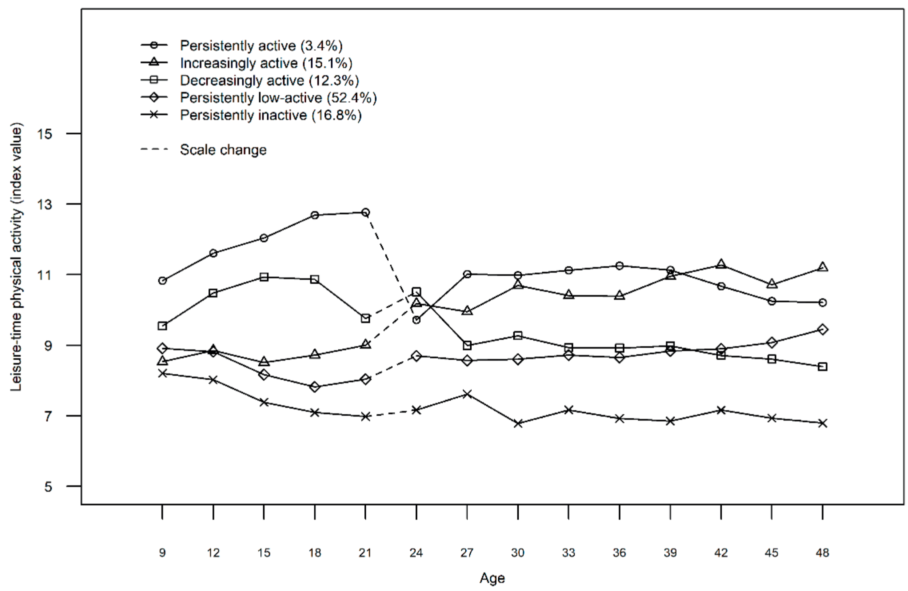
sd standard deviation; LTPA Leisure-time physical activity; FVC Fruit and vegetable consumption; BMI Body mass index. [a] p-value for sex difference (t-test).

3.2. Fruit and Vegetable Consumption of Males Across the Leisure-Time Physical Activity Trajectories

Four LTPA trajectories were identified for males: Persistently low-active (40.9%), decreasingly active (15.7%), increasingly active (31.1%), and persistently active (12.3%) (Figure 1A). More detailed description of the LTPA trajectories is presented in Supplement 1 and the selection of the final number of classes is presented in Table 2. The lowest level of FVC was found for males on the persistently low-active trajectory at nearly all ages (Figure 2A,B). Compared to those following the persistently active trajectory, the FVC of the persistently low-active males was significantly lower (p = [0.000, 0.015]) at half the ages studied (12, 15, 18, 21, 24, 36, and 39 years) (Table 3). In general, the level of FVC declined during adolescence (age 12-18 years) across all the LTPA trajectories (Figure 2A), but increased among the increasingly active, as well as low active (age 33–42) and decreasingly active males (age 42–48) in adulthood (Figure 2B).



(**A**) Males ($n = 1727$)



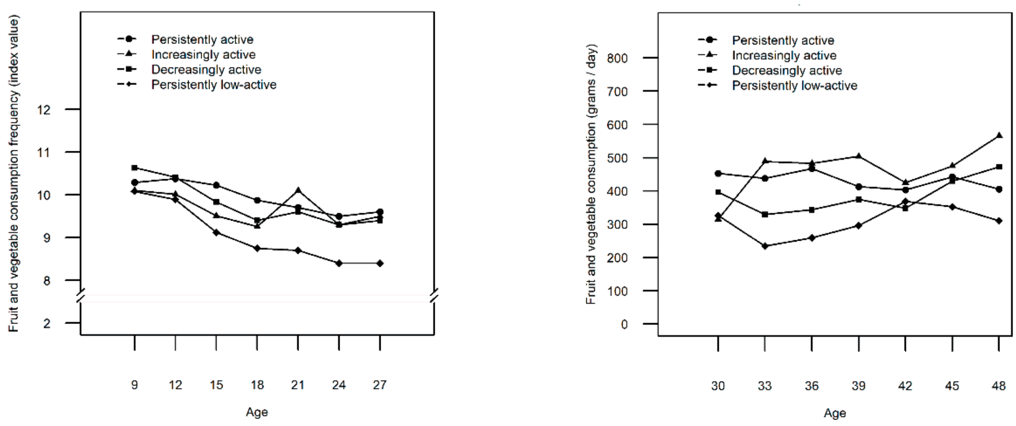
(**B**) Females ($n = 1809$)

Figure 1. Leisure-time physical activity trajectories for males (n = 1727) (**A**) and females (n = 1809) (**B**).

Table 2. Latent profile analyses for leisure-time physical activity in males (n = 1727) and females (n = 1809).

	AIC	BIC	ABIC	VLMR	LMR	BLRT	Entropy	Class Sizes (%) [a]	AvePP	The Number of Random Start Values and Final Iterations
Males										
1	32128	32281	32192	-	-	-	-	-	-	500, 20
2	30662	30897	30760	< 0.001	< 0.001	< 0.001	0.78	73.7%, 26.3%	0.95, 0.90	500, 20
3	30342	30658	30474	0.01	0.011	< 0.001	0.63	43.4%, 40.2%. 16.4%	0.83, 0.78, 0.89	500, 20
4	**30139**	**30537**	**30305**	**< 0.001**	**0.001**	**< 0.001**	**0.64**	**40.9%, 31.1%, 15.7%, 12.3%**	**0.80, 0.75, 0.72, 0.85**	**1000, 40**
5	30082	30562	30282	0.198	0.202	< 0.001	0.59	32.2%, 23.6%, 17.2%, 15.7%, 11.3%	0.65, 0.75, 0.72, 0.73, 0.85	1000, 40
6	30021	30583	30256	0.494	0.498	< 0.001	0.58	31.3%, 16.9%, 16.4%, 16.2%, 9.9%, 9.2%	0.64, 0.72, 0.68, 0.69, 0.81, 0.74	1000, 40
Females										
1	34757	34911	34822	-	-	-	-	-	-	500, 20
2	33634	33871	33734	< 0.001	< 0.001	< 0.001	0.83	84.0%, 16.0%	0.96, 0.89	500, 20
3	33268	33587	33403	< 0.001	< 0.001	< 0.001	0.64	57.5%, 30.6%, 11.9%	0.82, 0.81, 0.89	500, 20
4	33147	33548	33316	0.615	0.617	< 0.001	0.66	49.8%, 33.5%, 12.5%, 4.2%	0.79, 0.80, 0.77, 0.82	1000, 40
5	33018	33502	33223	0.183	0.184	< 0.001	0.66	52.4%, 16.8%, 15.1%, 12.3%, 3.4%	0.77, 0.79, 0.76, 0.77, 0.87	2000, 80
6	32963	33530	33202	0.322	0.324	< 0.001	0.60	41.7%, 15.7%, 15.0%, 14.1%, 10.0%, 3.5%	0.69, 0.76, 0.67, 0.72, 0.75, 0.85	2000, 80

[a] Final class proportions for the tested latent class models based on estimated posterior probabilities. AIC Akaike's information criterion; BIC Bayesian information criterion; BIC sample-size adjusted Bayesian information criterion; VLMR Vuong-Lo-Mendell-Rubin likelihood ratio test; LMR Lo-Mendell-Rubin adjusted LRT test; BLRT Parametric bootstrapped likelihood ratio test. AvePP Average posterior probabilities for most likely latent class membership. The class solution considered optimal is presented in bold.



(**A**) In childhood and adolescence (**B**) In adulthood

Figure 2. Mean fruit and vegetable consumption in different leisure-time physical activity trajectories among males from ages 9 to 27 years (**A**) and 30 to 48 years (**B**).

During childhood and adolescence (at ages 9–18), the highest mean values of FVC were found for males on the persistently or decreasingly active trajectory (Figure 2A). However, from age 33 onward, the highest mean values of FVC was observed in the increasingly active males (Figure 2B). When compared to the increasingly active males, those who were persistently active had significantly higher FVC at ages 15 and 18 (p = [0.003, 0.032]), after which no significant difference in FVC was observed between these two trajectories (Table 3). The participants on the increasingly active and persistently low-active trajectories showed similar levels of FVC in childhood and adolescence (at ages 9–18). However, the two trajectories showed a significant difference in FVC (p = [0.000, 0.020]) in favor of the increasingly active trajectory in adulthood (ages 21, 24, 36, 39, and 45) (Table 3). Concurrently, males on the decreasingly active trajectory showed higher FVC than those on the low-active trajectory up to age 24 (p = [0.006, 0.042]), but no longer in middle age (Table 3).

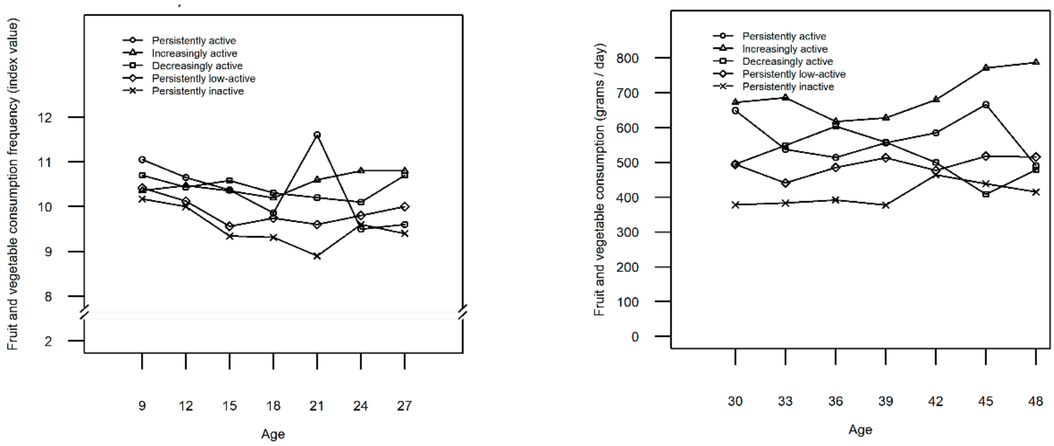
Table 3. Mean fruit and vegetable consumption across the leisure-time physical activity trajectories.

	Mean FVC in LTPA classes in 1980–1989 [a] (SE)							Mean FVC in LTPA classes in 2007–2011 [b] (SE)						
Age in years	9	12	15	18	21	24	27	30	33	36	39	42	45	48
Sample size, males	777	1022	957	837	487	491	325	140	244	240	287	276	296	116
Sample size, females	802	1038	1068	987	614	618	443	156	323	341	362	375	365	169
Males:														
1 Persistently active	10.3 (0.2)	10.4 (0.2)	10.2 (0.2)	9.9 (0.2)	9.7 (0.3)	9.5 (0.3)	9.6 (0.6)	452.8 (55.7)	437.9 (92.6)	467.5 (37.5)	413.1 (35.0)	403.1 (55.8)	442.7 (67.6)	405.3 (101.4)
2 Increasingly active	10.1 (0.1)	10.0 (0.2)	9.5 (0.2)	9.3 (0.2)	10.1 (0.3)	9.3 (0.3)	9.5 (0.6)	315.1 (48.9)	488.7 (87.3)	483.1 (34.3)	504.1 (47.8)	424.8 (33.1)	475.1 (33.5)	565.8 (109.3)
3 Decreasingly active	10.6 (0.2)	10.4 (0.2)	9.8 (0.2)	9.4 (0.3)	9.6 (0.3)	9.3 (0.3)	9.4 (0.8)	396.4 (59.2)	329.2 (68.9)	343.3 (54.3)	374.4 (47.4)	347.9 (74.0)	430.0 (75.7)	472.5 (99.5)
4 Persistently low-active	10.1 (0.1)	9.9 (0.1)	9.1 (0.1)	8.7 (0.1)	8.7 (0.2)	8.4 (0.2)	8.4 (0.3)	326.1 (57.9)	234.4 (115.5)	259.3 (41.4) [c]	295.8 (22.5)	368.6 (23.4)	352.4 (22.0)	310.2 (61.3)
Statistically significant mean differences in FVC between LTPA classes 1–4 (Z-score test)		4 < 3 * 4 < 1 *	2 < 1 ** 4 < 3 ** 4 < 1 ***	2 < 1 * 4 < 3 * 4 < 1 ***	4 < 3 * 4 < 2 *** 4 < 1 **	4 < 3 * 4 < 2 ** 4 < 1 **				3 < 2 * 4 < 2 *** 4 < 1 **	4 < 2 ** 4 < 1 **		4 < 2 **	
Females:														
1 Persistently active	11.0 (0.3)	10.7 (0.3)	10.4 (0.3)	9.9 (0.4)	11.6 [c] (0.8)	9.5 (0.6)	9.6 (0.7)	649.2 (156.5)	537.2 (96.5)	514.2 (46.4)	556.3 (83.1)	584.8 (103.8)	666.5 (75.7)	490.4 [c] (58.0)
2 Increasingly active	10.4 (0.2)	10.5 (0.2)	10.4 (0.2)	10.2 (0.3)	10.6 (0.4)	10.8 (0.3)	10.8 [c] (0.3)	672.8 (90.6)	686.4 (67.2)	617.7 (52.5)	628.2 (67.1)	680.1 (59.1)	771.1 (73.0)	787.2 [c] (75.0)
3 Decreasingly active	10.7 (0.2)	10.4 (0.1)	10.6 (0.2)	10.3 (0.2)	10.2 (0.5)	10.1 (0.3)	10.7 (0.3)	495.5 (69.7)	548.8 (55.7)	603.7 (43.6)	557.7 (53.3)	499.5 (65.5)	408.3 (82.3)	478.3 (111.0)
4 Persistently low-active	10.4 (0.1)	10.1 (0.1)	9.6 (0.1)	9.7 (0.1)	9.6 (0.2)	9.8 (0.1)	10.0 (0.2)	494.4 (47.0)	441.3 (68.5)	485.3 (37.4)	513.5 (37.2)	476.8 (30.1)	517.8 (24.4)	515.4 (39.9)
5 Persistently inactive	10.2 (0.2)	10.0 (0.2)	9.3 (0.2)	9.3 (0.2)	8.9 (0.3)	9.6 (0.3)	9.4 (0.4)	378.1 (233.4)	383.3 (73.8)	392.3 (50.7)	377.4 (32.1)	464.4 (41.4)	438.8 (40.7)	415.4 (74.1)
Statistically significant mean differences in FVC between LTPA classes 1–5 (Z-score test)	5 < 1 * 5 < 3 *		4 < 1 * 4 < 2 ** 4 < 3 *** 5 < 1 ** 5 < 2 *** 5 < 3 ***	4 < 3 * 5 < 2 ** 5 < 3 **	4 < 1 * 4 < 2 * 5 < 1 * 5 < 2 *** 5 < 3 *	4 < 2 ** 5 < 2 **	4 < 2 * 4 < 3 * 5 < 2 ** 5 < 3 **		3 < 2 * 5 < 2 **	5 < 2 ** 5 < 3 **	5 < 1 * 5 < 4 * 5 < 2 ** 5 < 3 **	3 < 2 * 4 < 2 ** 5 < 2 **	3 < 1 * 3 < 2 ** 4 < 2 ** 5 < 1 ** 5 < 2 ***	1 < 2 ** 3 < 2 * 4 < 2 ** 5 < 2 **

FVC Fruit and vegetable consumption; LTPA Leisure-time physical activity. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. [a] At ages 9-27 FVC was expressed with index (range: 2-12). The model was adjusted for BMI at ages 9-27, for mothers' education (years) at ages 9-18, and for participants' education (level) at ages 21-27. [b] At ages 30-48 FVC was expressed in grams of fruits and vegetables consumed in a day. The model was adjusted for participants' education (years), BMI, and total energy intake at ages 30-48. [c] The residual variances were fixed to a value with lowest Akaike's Information Criterion.

3.3. Fruit and Vegetable Consumption of Females Across the Leisure-Time Physical Activity Trajectories

Among females, five LTPA trajectories were identified: Persistently inactive (16.8%), persistently low-active (52.4%), decreasingly active (12.3%), increasingly active (15.1%), and persistently active (3.4%) (Figure 1B). For a more detailed description of the LTPA trajectories and the selection of the final number of classes, see Supplement 1 and Table 2. The mean values of FVC were the lowest among the females on the persistently inactive trajectory at almost all ages (Figure 3A,B). These values were significantly lower than among those on the persistently active trajectory at ages 9, 15, 21, 39 and 45 (p = [0.007, 0.049]) (Table 3).



(**A**) In childhood and adolescence (**B**) In adulthood

Figure 3. Mean fruit and vegetable consumption in different leisure-time physical activity trajectories among females from ages 9 to 27 years (**A**) and 30 to 48 years (**B**).

Figure 3 shows that the FVC was highest among the females on the increasingly active trajectory in middle age (Figure 3B). From age 15 onward, FVC was higher among the females on the increasingly active trajectory when compared to the inactive trajectory (p = [0.000, 0.005]) (Table 3). FVC was also higher among the increasingly active than low-active females at ages 15, 21, 24, 27, 42, 45 and 48 (p = [0.002, 0.048]). Females following the decreasingly active trajectory had higher FVC than their inactive peers at ages 9, 15, 18, 21, 27, 36, and 39 (p = [0.000, 0.041]) or their low-active peers at ages 15, 18, and 27 (p = [0.000, 0.044]). However, these differences were no longer evident in late middle age. FVC was higher among females identified to the increasingly active trajectory than among females in the decreasingly active trajectory at ages 33, 42, 45, and 48 (p = [0.001, 0.044]), but not in childhood, adolescence or young adulthood.

4. Discussion

The aim of this study was to gain insight into the relationship between LTPA trajectories and FVC from childhood to middle age. The findings suggest that FVC is likely to be higher in individuals, especially males, who are persistently active from childhood to adulthood when compared to their persistently, less-active peers. These results mirror the findings from a previous longitudinal study suggesting that physical inactivity and unhealthy diet are predictive of each other in men [27]. While FVC in females under 15 and males under 21 on the increasingly active trajectories resembled that of their inactive and low-active counterparts, the increasers of LTPA ended up having the highest FVC in adulthood. This tendency was particularly evident among females. In turn, FVC was higher among the decreasingly active than inactive females up to age 39 after which their FVC no longer differed from one another. Similarly, after males turned 27, the FVC of the decreasingly active males was no longer significantly higher when compared to their low-active peers. The results are in line with previous findings, both cross-sectional [6] and longitudinal [14,28], confirming that higher FVC and LTPA tend to occur in the same individuals. The results also add to previous knowledge by showing how the changes in FVC closely parallel the distinctive contours of each LTPA trajectory over time at many age points.

The general tendency of FVC was declining across all the LTPA trajectory classes during teenage years after which the tendency changed. The only exception was the females following the decreasingly active trajectory with their FVC declining later. The same declining tendency of FVC during adolescence and young adulthood has been observed in a previous longitudinal study [10]. Even though the tendency of FVC might be declining during teenage years, recent evidence from time trend analyses shows how the overall daily FVC between years 2002–2010 has increased among European and US adolescents aged 11–, 13– and 15 years [29].

The present study suggests that FVC level is associated positively not only with persistent activity level, but also with changes in LTPA from childhood to middle age. For example, an increase in LTPA among the increasingly active males and females was observed in young adulthood simultaneously with the increase in FVC. However, among the increasingly active males, LTPA increased only during young adulthood (ages 18–24) with a momentary high peak of FVC at this age, while another, more continuous change towards higher FVC was not observed until later in adulthood. In Finland, most young adults move from the family home just between 18 and 24 years of age [30]. This sort of transition periods of life may change food choices [31] which might explain the momentary peak of higher FVC among the increasingly active males and possibly also among the persistently active females at the age of 21. In contrast, the increase initiated at the age of 18 in FVC among females in the increasingly active trajectory continued until the end of the study period. Women tend to abandon unhealthy behaviors in young adulthood more often than men [32], which might explain why the favorable co-variance in the two behaviors was continuous for females starting already from the age of 18. Additionally, adult women have more pronounced health beliefs, better nutritional knowledge and attach greater importance to a healthy diet than adult men [33–35] which might explain the more consistent increase between the two behaviors among the increasingly active women. These results reflect the findings from a previous longitudinal study concluding that an increase in physical activity, in contrast to a decrease in physical activity, is associated with greater improvements in diet quality [36].

Reciprocally, the FVC of the decreasingly active participants dropped to the level of the persistently inactive participants among females and low-active participants among males in adulthood. Thus, decreasing LTPA may pose an additional health risk, due to simultaneous detrimental changes in diet. All in all, only 22% of women and 14% of men in Finland attain the recommended intake of fruits and vegetables [37] with FVC remaining low also worldwide when compared to the recommended level [38]. However, the decreasingly active males of the current study managed to increase their FVC again after turning 40. Indeed, an increasing trend in FVC was not observed only among the increasingly active participants, but also among the persistently active females and persistently low-active and decreasingly active males in adulthood. An increasing trend in FVC during recent decades has been reported among Finnish adults [39,40]. The improved availability of fruits in Northern Europe [41] and the affordability of fruits and vegetables in high-income countries when compared to low-income countries [38] probably explains this positive trend in FVC. Also, having lunch in a staff canteen has been found to be associated with higher FVC and improved diet among Finnish adult employees [42], suggesting that endeavors put into developing healthier catering services in Finland may also play a role in improving adults' dietary behavior. Furthermore, the consistent effort put in developing nutrition policy and Finnish nutrition guidelines [43] might have an effect on the favorable development of FVC. For example, when comparing the food pyramid in the national dietary recommendations in 1998 [44] to the food pyramid in the latest recommendations in 2014 [45], the latter recommends higher consumption of fruits and vegetables. Also, the guidelines in 2005 [46] recommended a level of 400 grams of fruits and vegetables per day, while the recommended level is nowadays 500 grams [45]. Diet following Finnish nutrition recommendations has been found to be inversely associated with waist circumference and body fat percentage [47] suggesting that consuming fruits and vegetables according to recommendations improves health.

Previous studies highlight the importance of, e.g., BMI, socioeconomic status, living environment, perceived health, life events, and other factors in explaining levels of physical activity or FVC [38,48–52]. Although the models used in the present study were adjusted for BMI, education and total energy intake (only in adulthood), it should be borne in mind that factors other than the two behaviors studied here may explain why FVC was higher among the persistently and increasingly active than low-active or inactive participants. For example, being on an increasingly or persistently active trajectory may be an indicator of an overall positive health orientation [6], while being on an inactive or low-active trajectory could be an indicator of an overall negative health orientation. A previous study on participants aged 13 to 30 years of age supports this interpretation: The authors identified an overall unhealthy trajectory in which daily fruit intake and regular exercise decreased with higher rates of smoking and inebriation [14].

Since the development of the two behaviors seems to occur in tandem, future interventions should study whether to target these two behaviors simultaneously, or is it enough to target one of them and improvements in the other behavior will follow. So far, short term interventions studying the issue have had inconsistent findings with two concluding that improvements in physical activity do not lead to healthier diet [53,54], and another one showing that by increasing physical activity improvements in diet can be achieved, but only among boys [55]. Future studies should also investigate the factors that determine why certain people end up on unfavorable and others on favorable dietary and physical activity trajectories and what are the factors enabling the favorable changes of the two behaviors during the lifespan.

This study has several strengths, including a large sample size comprising six age cohorts, recruitment of participants from across Finland, a 30–year follow-up starting from childhood, and multiple follow-up measurements of LTPA and FVC. Together, these features of the YFS made it possible to study the complex relationship between LTPA and FVC during the life course. The use of a novel, data-driven statistical method enabled the identification of LTPA trajectories in which participants' LTPA developed similarly, while differing from those in the other trajectories [11]. As recommended in the previous literature, whole foods, here fruits and vegetables [56], were used as units of healthy nutrition [57] instead of specific nutrients (e.g., vitamin C). Moreover, the study utilized the STROBE-nut checklist (Supplement 2) and a modified version of the GRoLTS checklist (Supplement 3) for ensuring appropriate quality in reporting the results. The GRoLTS checklist was modified as not all the items in the list were suited to latent profile analyses, but instead to latent growth mixture modelling and latent class growth analyses.

This study has its limitations. LTPA and FVC were self-reported, which may produce biased results. There is a possibility for recall bias with light leisure-time physical activities being generally harder to recall than vigorous ones [58]. Social desirability bias, meaning the tendency to over-report desired behaviors and underreport undesired ones, is also present with self-reported data [59]. Self-reported physical activity is commonly estimated higher than objectively measured physical activity [60], and study participants, especially women, tend to overestimate their consumption of foods that are considered to be healthy [61]. After participants turned 30, the method used to assess diet changed from a simple 19–item form to a more comprehensive FFQ. The validity of the latter questionnaire is presumably higher than that of the former one as a previous study showed how a similar comprehensive FFQ as used in the current study performed more accurately than 7– and 16–item questionnaires [62]. However, these biases do not necessarily invalidate the results since the measurement instruments are used for ranking individuals and not analyzing the exact amount of fruits and vegetables consumed nor the exact intensity (low, moderate or vigorous) of physical activity. The sample was representative of the general Finnish population. Hence, the present results cannot be generalized to other populations, especially those in low- or middle-income countries or with diverse ethnic groups.

Trajectory modelling also has its limitations. For example, each trajectory is a description of the subgroup's mean behavior, and thus, no participant is likely to follow the identified trajectory precisely [63]. This is a reliability issue, especially in the small trajectory classes. Also, the mean FVC across the LTPA trajectories might not be reliable at those five age points where the residual variances of the FVC needed to be fixed to a value with the lowest Akaike's Information Criterion in order to get a result (see FVC mean values marked with c in Table 3). Especially the persistently active women at the age of 21 and at the age of 48 seemed to have a deviant shift in their FVC mean values (Figure 3). On the other hand, this trajectory class was extremely small (3.4% of the sample) which is why a change in the answers of just a few participants may, indeed, change the mean FVC considerably. Finally, although the final number of LTPA trajectory classes was based on objective index values, subjective interpretation was also used, a procedure that could induce selection bias.

5. Conclusions

A parallel relationship from childhood to middle age was found between the LTPA trajectories and FVC. The results support that of previous longitudinal research showing that LTPA behavior and FVC may facilitate each other [64] and, in turn, decreasing LTPA may be an indicator for an additional health risk, due to simultaneous detrimental changes in diet. While the most recent measurements showed improvements in FVC across many of the LTPA trajectories, a decreasing tendency in FVC was observed across nearly all the LTPA trajectories during teenage years and the inactive, low-active and decreasingly active participants generally showed the lowest levels of FVC in adulthood. Putting effort into adopting or maintaining a physically active lifestyle along with healthy dietary habits, starting from adolescence, could be important for health later in life. To achieve the favorable changes in these behaviors, cross-government and multisectoral approaches that facilitate the integration of physical activity and higher FVC in multiple daily settings are needed.

Supplementary Materials: The following are available online at http://www.mdpi.com/1660-4601/16/22/4437/s1, Supplement 1: Statistical analyses used to identify leisure-time physical activity trajectories and their descriptions, Supplement 2: Filled checklist of strengthening the reporting of observational studies in epidemiology and nutritional epidemiology, Supplement 3: Filled checklist of guidelines for reporting on latent trajectory studies.

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Supplement 1. Statistical analyses used to identify leisure-time physical activity trajectories and their descriptions.

METHODS: LEISURE-TIME PHYSICAL ACTIVITY TRAJECTORIES

Statistical analysis used to identify leisure-time physical activity trajectories

Latent profile analysis, a type of finite mixture modelling, was conducted separately for males and females to identify distinct LTPA trajectories from childhood to adulthood. Before modelling commenced, the longitudinal data were rearranged so that time points referred to ages instead of measurement years. Because the content of the LTPA questionnaires changed in 1992, overlapping items were recoded for missing values. After recoding, the LTPA questionnaires were similar in content from age 9 to 21 and from age 24 to 48. The latent profile analysis was based on the means of the LTPA outcome measures from age 9 to 48, and error variances were assumed to be equal across classes.

Models with one to six LTPA classes were fitted. Statistical criteria for the goodness-of-fit of each model was used to decide the number of classes. The criteria evaluated in this study were Akaike's information criterion (AIC), the Bayesian information criterion (BIC) and the sample-size adjusted BIC (ABIC). For all three criteria, the lower the value, the better the fit of the model. In addition, the Vuong-Lo-Mendell-Rubin likelihood ratio test (VLMR), Lo-Mendell-Rubin adjusted likelihood ratio test (LMR) and parametric bootstrapped likelihood ratio test (BLRT) statistical tests were used to determine the optimum number of classes. The estimated model was compared to the model with one class less, a lower p-value indicating that the model with one class less is rejected in favour of the estimated model [1]. Entropy values and the average posterior probabilities (AvePP) for most likely latent class membership were used to evaluate the quality of the classification. Both measures ranged from 0 to 1, with the value 1 indicating a perfect classification. Values higher than 0.7 were considered acceptable for the average posterior probabilities [2, 3]. Missing data were assumed to be missing at random (MAR). Model parameters were estimated by using the full information maximum likelihood (FIML) method with robust standard errors, thereby enabling use of all the available data.

RESULTS: LEISURE-TIME PHYSICAL ACTIVITY TRAJECTORIES

Leisure-time physical activity trajectories of males from childhood to adulthood

The following four LTPA trajectory classes were identified for males: persistently low-active (40.9 %), decreasingly active (15.7 %), increasingly active (31.1 %), and persistently active (12.3 %) (Fig. 1A). At each additional step in the modelling, the ABIC continued to decrease and the p-value of the BLRT remained low (<.001) (Table 2). However, in the five-class solution, the AvePP value for one of the latent classes fell below the acceptable level (<.7), the p-values of the VLMR and LMR were higher than .05 and the BIC started to rise again, hence the four-class solution was considered optimal.

Males on the persistently active trajectory remained the most active (mean LTPA index value 11.6) while those on the persistently low-active trajectory remained the least active almost throughout the study period (mean LTPA index value 7.8). LTPA decreased considerably between ages 12 (mean LTPA index value 9.2; 95% CI 8.9-9.4) and 21 (mean LTPA index value 7.1; 95% CI 6.8-7.3) among the low-active participants. A decline in LTPA for those on the decreasingly active trajectory also begun around age 12 (mean LTPA index value 11.5; 95% CI 11.2-11.8), continuing until age 48 (mean LTPA index value 7.5; 95% CI 6.3-8.7) and thereafter dropping to the level of the low-active participants (mean LTPA index value 7.9; 95% CI 7.4-8.4). At age 18, the LTPA level of the increasers reached its lowest point (mean LTPA index value 8.6; 95% CI 8.3-9.0), and at the age of 24 its highest point (mean LTPA index value 10.3; 95% CI 9.5-11.1) (Fig. 1A).

Leisure-time physical activity trajectories of females from childhood to adulthood

The following five LTPA trajectory classes were identified for females: persistently inactive (16.8 %), persistently low-active (52.4 %), decreasingly active (12.3 %), increasingly active (15.1 %), and persistently active (3.4 %) (Fig. 1B). The p-values of the VLMR and LMR were below .05 only up to the three-class solution. However, since the ABIC continued to decrease substantially and the p-value of the BLRT was lower than .001 in each additional step, the modelling was continued up to the six-class solution (Table 2). At the six-class solution, the AvePP fell below the acceptable level (<0.7) in two of the latent classes, and the BIC started to increase again; hence, the five-class solution was considered optimal.

Among females, the biggest changes in LTPA occurred before age 27, after which it stabilized. The increasingly active trajectory was an exception, showing a continuously increasing trend from childhood to adulthood: the mean LTPA index value increased from 8.5 (95% CI: 8.1-9.0) to 11.2 (95% CI: 9.9-12.5) between ages 9 and 48. The increasers were the second least active participants at age 9, but around age 40 they became the most active, exceeding the LTPA level of the persistently active participants. For those on the decreasingly active trajectory, the decline in LTPA started at age 18 (LTPA index value 10.9; 95% CI: 9.6-12.1) and continued to the end of the follow-up at age 48 (LTPA index value 8.4; 95% CI: 7.3-9.5). The participants on the persistently inactive trajectory remained the least active, showing a slightly decreasing tendency in LTPA across the study period (mean LTPA index value 7.2). A decrease in LTPA was also seen among those on the low-active trajectory from ages 9 (LTPA index value 8.9; 95% CI: 8.6-9.2) to 18 (LTPA index value 7.8; 95% CI: 7.6-8.1), with slight increase in mid-adulthood (Fig. 1B).

Abbreviations

ABIC: Adjusted Bayesian information criterion

AIC: Akaike's information criterion

AvePP: Average posterior probabilities

BIC: Bayesian information criterion CI: Confidence interval

BLRT: Parametric bootstrapped likelihood ratio test

LMR: Lo-Mendell-Rubin adjusted likelihood ratio test

LTPA: Leisure-time physical activity

VLMR: Vuong-Lo-Mendell-Rubin likelihood ratio test

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Supplement 2. Filled checklist of strengthening the reporting of observational studies in epidemiology and nutritional epidemiology.

Item	Item nr	STROBE recommendations	Extension for Nutritional Epidemiology studies (STROBE-nut)	Reported on page #
Title and abstract	1	(a) Indicate the study's design with a commonly used term in the title or the abstract. (b) Provide in the abstract an informative and balanced summary of what was done and what was found.	**nut-1** State the dietary/nutritional assessment method(s) used in the title, abstract, or keywords.	a) 1 b) 1 nut-1) 1
Introduction				
Background rationale	2	Explain the scientific background and rationale for the investigation being reported.		1-2
Objectives	3	State specific objectives, including any pre-specified hypotheses.		2
Methods				
Study design	4	Present key elements of study design early in the paper.		2
Settings	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection.	**nut-5** Describe any characteristics of the study settings that might affect the dietary intake or nutritional status of the participants, if applicable.	2 nut-5)not applicable

Item	Item nr	STROBE recommendations	Extension for Nutritional Epidemiology studies (STROBE-nut)	Reported on page #
Participants	6	a) Cohort study—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up. Case-control study—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls. Cross-sectional study—Give the eligibility criteria, and the sources and methods of selection of participants. (b) Cohort study—For matched studies, give matching criteria and number of exposed and unexposed. Case-control study—For matched studies, give matching criteria and the number of controls per case.	**nut-6** Report particular dietary, physiological or nutritional characteristics that were considered when selecting the target population.	a) 2 b) - nut-6) 3
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable.	**nut-7.1** Clearly define foods, food groups, nutrients, or other food components. **nut-7.2** When using dietary patterns or indices, describe the methods to obtain them and their nutritional properties.	2-3 nut-7.1) 3 nut-7.2) 3

Item	Item nr	STROBE recommendations	Extension for Nutritional Epidemiology studies (STROBE-nut)	Reported on page #
Data sources - measurements	8	For each variable of interest, give sources of data and details of methods of assessment (measurement).Describe comparability of assessment methods if there is more than one group.	**nut-8.1** Describe the dietary assessment method(s), e.g., portion size estimation, number of days and items recorded, how it was developed and administered, and how quality was assured. Report if and how supplement intake was assessed. **nut-8.2** Describe and justify food composition data used. Explain the procedure to match food composition with consumption data. Describe the use of conversion factors, if applicable. **nut-8.3** Describe the nutrient requirements, recommendations, or dietary guidelines and the evaluation approach used to compare intake with the dietary reference values, if applicable. **nut-8.4** When using nutritional biomarkers, additional ly use the STROBE Extension for Molecular Epidemiology (STROBE-ME). Report the type of biomarkers used and their usefulness as dietary exposure markers. **nut-8.5** Describe the assessment of nondietary data (e.g., nutritional status	2-3 nut-8.1) 3 nut-8.2) - nut-8.3) not applicable nut-8.4) not applicable nut-8.5) - nut-8.6) 3

Item	Item nr	STROBE recommendations	Extension for Nutritional Epidemiology studies (STROBE-nut)	Reported on page #
			and influencing factors) and timing of the assessment of these variables in relation to dietary assessment. **nut-8.6** Report on the validity of the dietary or nutritional assessment methods and any internal or external validation used in the study, if applicable.	
Bias	9	Describe any efforts to address potential sources of bias.	**nut-9** Report how bias in dietary or nutritional assessment was addressed, e.g., misreporting, changes in habits as a result of being measured, or data imputation from other sources	2-4 nut-9) 3
Study Size	10	Explain how the study size was arrived at.		2-3
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why.	**nut-11** Explain categorization of dietary/nutritional data (e.g., use of N-tiles and handling of nonconsumers) and the choice of reference category, if applicable.	2-4 + Supplement 1 and Table 2 nut-11) not applicable
Statistical Methods	12	(a) Describe all statistical methods, including those used to control for confounding (b) Describe any methods used to examine subgroups and interactions.	**nut-12.1** Describe any statistical method used to combine dietary or nutritional data, if applicable.	a-b) 3-4 + Supplement 1 and Table 2 c) 4

Item	Item nr	STROBE recommendations	Extension for Nutritional Epidemiology studies (STROBE-nut)	Reported on page #
		(c) Explain how missing data were addressed. (d) Cohort study—If applicable, explain how loss to follow-up was addressed. Case-control study—If applicable, explain how matching of cases and controls was addressed. Cross-sectional study—If applicable, describe analytical methods taking account of sampling strategy. (e) Describe any sensitivity analyses.	**nut-12.2** Describe and justify the method for energy adjustments, intake modeling, and use of weighting factors, if applicable. **nut-12.3** Report any adjustments for measurement error, i.e,. from a validity or calibration study.	d) - e) – nut-12.1) 4 nut-12.2) 3-4 nut-12.3) -
Results				
Participants	13	(a) Report the numbers of individuals at each stage of the study—e.g., numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analyzed. (b) Give reasons for non-participation at each stage. (c) Consider use of a flow diagram.	**nut-13** Report the number of individuals excluded based on missing, incomplete or implausible dietary/nutritional data.	a) 4-5 b) 2 c) – nut-13) 4-5
Descriptive data	14	(a) Give characteristics of study participants (e.g., demographic, clinical,	**nut-14** Give the distribution of participant characteristics across the	a) 5, Table1

Item	Item nr	STROBE recommendations	Extension for Nutritional Epidemiology studies (STROBE-nut)	Reported on page #
		social) and information on exposures and potential confounders (b) Indicate the number of participants with missing data for each variable of interest (c) Cohort study—Summarize follow-up time (e.g., average and total amount)	exposure variables if applicable. Specify if food consumption of total population or consumers only were used to obtain results.	b) Table 1 c) 4-5 nut-14) Table 1
Outcome data	15	Cohort study—Report numbers of outcome events or summary measures over time. Case-control study—Report numbers in each exposure category, or summary measures of exposure. Cross-sectional study—Report numbers of outcome events or summary measures.		5-10 + supplement 1 and Table 2
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included. (b) Report category boundaries when continuous variables were categorized.	**nut-16** Specify if nutrient intakes are reported with or without inclusion of dietary supplement intake, if applicable.	a) 5-9+ supplement 1, Table 2 and Table 3, figures 1-3 b) – c) –

Item	Item nr	STROBE recommendations	Extension for Nutritional Epidemiology studies (STROBE-nut)	Reported on page #
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period.		nut-16) not applicable
Other analyses	17	Report other analyses done—e.g., analyses of subgroups and interactions and sensitivity analyses.	**nut-17** Report any sensitivity analysis (e.g., exclusion of misreporters or outliers) and data imputation, if applicable.	- nut-17) -
Discussion				
Key results	18	Summarize key results with reference to study objectives.		10 and 12 (conclusions)
Limitation	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias.	**nut-19** Describe the main limitations of the data sources and assessment methods used and implications for the interpretation of the findings.	11-12 nut-19) 11-12
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence.	**nut-20** Report the nutritional relevance of the findings, given the complexity of diet or nutrition as an exposure.	10-12 nut-20) 10-12
Generalizability	21	Discuss the generalizability (external validity) of the study results.		12
Other information				

Item	Item nr	STROBE recommendations	Extension for Nutritional Epidemiology studies (STROBE-nut)	Reported on page #
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based.		13
Ethics			**nut-22.1** Describe the procedure for consent and study approval from ethics committee(s).	nut-22.1) 4
Supplementary material			**nut-22.2** Provide data collection tools and data as online material or explain how they can be accessed.	nut-22.2) Supplements 1-3

Reference: Lachat C et al. (2016) STrengthening the Reporting of OBservational studies in Epidemiology – Nutritional Epidemiology (STROBE-nut): an extension of the STROBE statement. Plos Medicine 13(6) http://dx.doi.org/10.1371/journal.pmed.1002036 pdf or online version.

Supplement 3. Filled checklist of guidelines for reporting on latent trajectory studies*.

	Checklist Item	Reported
1.	Is the metric of time used in the statistical model reported?	Yes
2.	Is information presented about the mean and variance of time within a wave?	No
3a.	Is the missing data mechanism reported?	Yes
3b.	Is a description provided of what variables are related to attrition/missing data?	Yes
3c.	Is a description provided of how missing data in the analyses were dealt with?	Yes
4.	Is information about the distribution of the observed variables included?	Yes
5.	Is the software mentioned?	Yes
6a.	Are alternative specifications of within-class heterogeneity considered (e.g., LGCA vs. LGMM) and clearly documented? If not, was sufficient justification provided as to eliminate certain specifications from consideration?	LGCA nor LGMM were not used. However, LTPA trajectories have been identified from the same data in previous paper by using group-based trajectory modelling.** Those trajectories are in line with the ones identified in this study.
6b.	Are alternative specifications of the between-class differences in variance–covariance matrix structure considered and clearly documented? If not, was sufficient justification provided as to eliminate certain specifications from consideration?	LGCA nor LGMM were not used.

	Checklist Item	Reported
7.	Are alternative shape/functional forms of the trajectories described?	Not applicable in latent profile analyses.
8.	If covariates have been used, can analyses still be replicated?	Yes
9.	Is information reported about the number of random start values and final iterations included?	Yes
10.	Are the model comparison (and selection) tools described from a statistical perspective?	Yes
11.	Are the total number of fitted models reported, including a one-class solution?	Yes
12.	Are the number of cases per class reported for each model (absolute sample size, or proportion)?	Yes
13.	If classification of cases in a trajectory is the goal, is entropy reported?	Yes
14a.	Is a plot included with the estimated mean trajectories of the final solution?	Yes
14b.	Are plots included with the estimated mean trajectories for each model?	No

	Checklist Item	Reported
14c.	Is a plot included of the combination of estimated means of the final model and the observed individual trajectories split out for each latent class?	No
15.	Are characteristics of the final class solution numerically described (i.e., means, *SD/SE*, *n*, CI, etc.)?	Yes
16.	Are the syntax files available (either in the appendix, supplementary materials, or from the authors)?	Yes, from the authors

* See reference: van de Schoot, R., Sijbrandij, M., Winter, S D., Depaoli. S. & Vermunt. J K. The GRoLTS-Checklist: Guidelines for Reporting on Latent Trajectory Studies. Structural Equation Modeling. 2017; 24, 451-467.

** See reference: Rovio, S. et al. Longitudinal physical activity trajectories from childhood to adulthood and their determinants: The Young Finns Study. Scand J Med Sci Sports. 2018; 28, 1073-1083.

IV

LIFE COURSE LEISURE-TIME PHYSICAL ACTIVITY TRAJECTORIES IN RELATION TO HEALTH-RELATED BEHAVIORS IN ADULTHOOD: THE CARDIOVASCULAR RISK IN YOUNG FINNS STUDY

by

Lounassalo, I., Hirvensalo, M., Palomäki, S., Salin, K., Tolvanen, A., Pahkala, K., Rovio, S., Fogelholm, M., Yang, X., Hutri-Kähönen, N., Raitakari, O. T., & Tammelin, T. H. (2021)

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RESEARCH ARTICLE Open Access

Life-course leisure-time physical activity trajectories in relation to health-related behaviors in adulthood: the Cardiovascular Risk in Young Finns study

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Abstract

Background: Evidence on whether leisure-time physical activity (LTPA) facilitates individuals' adoption of multiple healthy behaviors remains scarce. This study investigated the associations of diverse longitudinal LTPA trajectories from childhood to adulthood with diet, screen time, smoking, binge drinking, sleep difficulties, and sleep duration in adulthood.

Methods: Data were drawn from the Cardiovascular Risk in Young Finns Study. Participants were aged 9–18 years ($N = 3553$; 51% females) in 1980 and 33–49 years at the latest follow-up in 2011. The LTPA trajectories were identified using a latent profile analysis. Differences in self-reported health-related behaviors across the LTPA trajectories were studied separately for women and men by using the Bolck-Croon-Hagenaars approach. Models were adjusted for age, body mass index, education level, marital status, total energy intake and previous corresponding behaviors.

Results: Persistently active, persistently low-active, decreasingly and increasingly active trajectories were identified in both genders and an additional inactive trajectory for women. After adjusting the models with the above-mentioned covariates, the inactive women had an unhealthier diet than the women in the other trajectories ($p < 0.01$; effect size (ES) > 0.50). The low-active men followed an unhealthier diet than the persistently and increasingly active men ($p < 0.01$; ES > 0.50). Compared to their inactive and low-active peers, smoking frequency was lower in the increasingly active women and men ($p < 0.01$; ES > 0.20) and persistently active men ($p < 0.05$; ES > 0.20). The increasingly active men reported lower screen time than the low-active ($p < 0.001$; ES > 0.50) and persistently active ($p < 0.05$; ES > 0.20) men. The increasingly and persistently active women reported fewer sleep difficulties than the inactive ($p < 0.001$; ES > 0.80) and low-active ($p < 0.05$; ES > 0.50 and > 0.80, respectively) women. Sleep duration and binge drinking were not associated with the LTPA trajectories in either gender, nor were sleep difficulties in men and screen time in women.

(Continued on next page)

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(Continued from previous page)
Conclusions: Not only persistently higher LTPA but also an increasing tendency to engage in LTPA after childhood/adolescence were associated with healthier diet and lower smoking frequency in both genders, having less sleep difficulties in women and lower screen time in increasingly active men. Inactivity and low activity were associated with the accumulation of several unhealthy behaviors in adulthood. Associations were stronger in women.

Keywords: Physical activity, Diet, Sleep, Alcohol, Binge drinking, Smoking, Screen time, Longitudinal, Trajectory, Life-course

Background

Non-communicable diseases, such as cardiovascular disease, diabetes mellitus, and several cancers, cause over 70% of deaths worldwide with unhealthy behaviors usually causing these diseases [1]. Physical activity (PA), dietary behavior, smoking and consuming alcohol are traditionally seen as the major four behaviors impacting health [2]. Lately, sleeping and sedentary behavior have been identified as important additional behaviors impacting it as well [3–6]. Physical inactivity, unhealthy diet, regular smoking, and binge drinking [7], shortened [4] and prolonged sleep duration [3, 4], insomnia [5], and sedentary behavior [6, 8] (e.g., prolonged television viewing [9] and total screen time [10]) have been found to be associated with a higher risk of non-communicable diseases and mortality.

Behavioral risk factors tend to accumulate to same individuals which may have synergistic effects on health [11]. A study examining smoking, alcohol intake, diet, PA, television viewing, and sleep together showed that a combination of multiple health-compromising behaviors was strongly associated with cardiovascular disease mortality and all-cause mortality [12] while a combination of multiple health-enhancing behaviors have been found to decrease the relative risk for all-cause mortality [13]. Thus, promoting the adoption of multiple healthy behaviors is essential for improving public health.

Changing one behavior may translate into changing other behavior as well, especially if both behaviors are health-enhancing or health-risky [14]. Previous evidence suggests that PA might play an important role for adopting to multiple healthy lifestyle factors, e.g. eating healthier [15, 16]. A longitudinal study found that adults who increased their PA also improved their diet when compared to their decreasingly active peers [17], whereas low PA was found to associate with higher risk of sleep problems and incident short sleep time among middle-aged and older adults [18]. Additionally, physical inactivity in adolescence predicted smoking [19] and weekly alcohol intoxication in young adulthood, especially in women [20]. Our previous longitudinal studies showed that persistently physically active adult women watched television less than low-active women [21], leisure-time physical activity (LTPA) evolved in tandem with fruit and vegetable consumption from childhood to adulthood [22], persistent inactivity was associated with smoking [23, 24] whereas, in contrast, persistent higher LTPA was associated with regular alcohol drinking [23].

However, previous research has mainly focused on the association of PA or LTPA with single health behavior. Moreover, longitudinal studies on whether a specific LTPA life-course developmental pathway facilitates the adoption of several other health-enhancing behaviors in adulthood are lacking. This study aimed to investigate whether cross-sectionally measured health-related behaviors in adulthood – including diet, screen time, smoking, binge drinking, sleep difficulties, and sleep duration – differ by LTPA pathways measured from childhood to adulthood in men and women. LTPA was defined as participation in PA and sport by querying intensity, duration and frequency of PA, and participation in organized sports. Occupational PA was not queried. Data-driven trajectory modeling [25] was chosen as the method for identifying LTPA pathways, as trajectories can yield novel information on the complexity of PA behavior [26].

Methods

Study design and participants

The data were drawn from the ongoing population-based longitudinal Cardiovascular Risk in Young Finns Study (YFS). The study involves five Finnish university cities (Helsinki, Kuopio, Oulu, Tampere, and Turku) and their rural surroundings. Participants with different socioeconomic backgrounds were randomly selected from the population register of these areas to produce a representative sample of Finnish children and adolescents [27]. In 1980, 3596 children and adolescents (boys and girls aged 3–18 years; 83% of those invited) participated in the baseline study. Follow-up studies have thus far been conducted in 1983, 1986, 1989, 1992, 2001, 2007 and 2011. The study sample comprised six cohorts aged 3, 6, 9, 12, 15 and 18 years at baseline and thus 33–49 years at the 2011 follow-up. The representativeness of the study population has been studied by comparing the baseline (1980) characteristics between the sample of the year 2001 and those lost to follow-up [27]. The results showed that participants were older and more often females than non-participants. No significant differences between the non-participants and participants were observed in LTPA, body mass index (BMI), or parental years of education. A more detailed description of the YFS protocol, attrition analysis and reasons for non-participation have been published previously [27].

Measurements

Life-course leisure-time physical activity

LTPA was parent-reported before turning 9 years of age and self-reported thereafter. To avoid biased results, parent-reported data were excluded from the present study. Participants with at least one measurement of self-reported LTPA ($N = 3553$) were included in the present study (see more in [Supplementary file 1]). Self-reported LTPA was treated as the exposure variable for other adulthood health-related behaviors. In the years 1980–1989, the LTPA questionnaire comprised items on the frequency and intensity of PA, habitual ways of spending leisure-time, and participation in sports-club training and sport competitions. After 1989, the questionnaire was slightly modified, as LTPA differs between school-aged children and adults. In the years 1992–2011, the LTPA questionnaire comprised items on the frequency and intensity of PA, frequency of vigorous PA, hours spent in vigorous PA, average duration of a PA session, and participation in organized PA. Occupational PA was not queried. Responses on each item were first recoded into three categories (1 = irregular activity / low activity / inactivity; 2 = regular weekly activity / moderate activity; 3 = regular daily activity / vigorous activity) and scores were then summed to create a LTPA index ranging from 5 to 15 [28]. The development of the index has been reported in detail elsewhere (see Table S1 and S2 in [23]).

In the YFS, the original aim of the LTPA index was not to measure the absolute amount or exposure to LTPA but rather to rank the participants according to their LTPA level. Previously conducted validation analyses show that the LTPA questionnaire is an acceptably valid subjective measure of LTPA [29–32]. Correlations between the LTPA index and indicators of exercise capacity (hypothetical maximal workload sustainable for 6 min) have been studied in subsamples of participants and found to be significant with medium effect sizes in childhood (girls: $r = 0.39$; boys: $r = 0.33$) and medium to large effect sizes in adulthood (women: $r = 0.49$; men: $r = 0.53$) [30]. The index also correlated with the total volume of movement assessed with accelerometers, including frequency, intensity, and duration of activity bouts ($r = 0.26–0.45$) [31], and with 7-day pedometer data on total steps and aerobic steps ($r = 0.25–0.31$) [32] with the effect sizes ranging from small to medium. In 1980, internal consistency coefficients, as indicators of reliability, varied from 0.44 to 0.69 in females and 0.49 to 0.76 in males, and in 2001, the corresponding values were 0.59 to 0.85 and 0.74 to 0.85 [30].

Measurements of health-related behaviors in adulthood

In 2011, the adulthood health-related behaviors assessed with self-reports were diet, screen time, smoking, binge drinking, sleep difficulties and sleep duration. These behaviors were treated as the outcome variables for the LTPA trajectories.

Diet was assessed with a validated Finnish self-administered food frequency questionnaire [33]. Participants reported the frequencies of their habitually consumed food and drink items. Average daily food intake was converted into grams by using the Finnish National Food Composition Database (Fineli®). A sum index indicating a healthy diet was created. It included foods considered healthy (whole grain products; fruits excluding fruit juice; vegetables and legumes excluding potatoes; fish; vegetable fats and oils) or unhealthy (red meat and meat products; sugared beverages; fried and deep-fried potatoes; desserts including budding, ice cream, biscuits, sweet pastry, chocolate and candy). Participants were first divided into quartiles (Q) based on their mean daily intake scores for each food item: the higher the consumption of healthy foods, the higher the score (Q1 = 0; Q2 = 1; Q3 = 2; Q4 = 3 points) and the higher the consumption of unhealthy foods, the lower the score (Q1 = 3; Q2 = 2; Q3 = 1; Q4 = 0 points). Points were then summed to create a diet index ranging from 0 to 27: the higher the value, the healthier the participant's diet.

Television viewing time and computer use were assessed with two questions: "How many hours per day on average day do you spend: 1) watching television and videos at home, and 2) using a computer at home?" Mean daily television and computer times were calculated separately ($[(5 \times \text{weekday}) + (2 \times \text{weekend})] / 7$) after which the mean values of the two sedentary behaviors were summed to form an index of daily screen time during leisure (hours/day).

The categories for current smoking status were: (1) non-smoker (never smoked), (2) former smoker (on strike or stopped smoking), (3) occasional smoker (less than once a week), and (4) regular smoker (once or more a week). Binge drinking was determined as consuming six or more alcoholic drinks on a single occasion. The categories for binge drinking frequency were: (1) six times a year or less, (2) one to three times a month, (3) once a week, and (4) twice a week or more often.

Sleep difficulties were assessed with Jenkins's scale which has proven valid and reliable [34, 35]. The scale comprises four items on sleep difficulties corresponding to the insomnia symptoms listed in the Diagnostic and Statistics Manual of Mental Disorders [36]. The four items assess problems in falling asleep, awakenings during sleep, difficulties staying asleep (including too-early awakenings), and feelings of tiredness after a normal night's sleep [34]. For participants who reported more than one symptom, their most frequent symptom was recorded as their degree of sleep difficulty. Sleep difficulty was categorized as 1) no sleep difficulty (≤ 1 night a week), 2) moderate sleep difficulty (2–4 nights a week), or 3) severe sleep difficulty (5–7 nights a week).

Hours of usual sleep duration per night were self-reported within half an hour accuracy. The recommended duration of sleep for young adults and adults is 7–9 h per night [37]. The results were reported as probabilities for meeting the sleep duration recommendation. A binary variable was created with 1 = meeting and 0 = not meeting the recommendation.

Covariates

Age, body mass index (BMI), level of education and marital status were elicited in 2011 and used as covariates, as they may affect health behaviors [38–41]. Total energy intake was used as a covariate for dietary behavior. Also, health behaviors in childhood, adolescence or young adulthood were used as covariates for the corresponding outcome health behaviors in adulthood, since previous behavior predicts similar behavior in the future [42–44]. A detailed description of the covariates can be found in supplementary material [Supplementary file 2].

Statistical analysis

Descriptive statistics were calculated by using IBM SPSS Statistics for Windows, version 24.0 (IBM Corp. Armonk, NY, USA) and expressed as means and standard deviations or as percentages. Differences in the study variables between women and men were tested by using an independent-samples t-test.

Further modeling was performed with Mplus, version 8.0 [45]. All analyses were performed separately for women and men due to previously observed sex differences in LTPA [24] and other health-related variables (Table 1). The specific LTPA trajectories for women and men used in the current study were earlier identified using latent profile analysis. For details on the statistical modeling, see supplementary material [Supplementary file 1] and previous papers ([22, 24]). In the trajectory modeling, missing data were assumed to be missing at random. Model parameters were estimated by using the full information maximum likelihood method with robust standard errors, which enabled use of all available data.

In the current study, mean differences in the diet index, screen time, smoking status, binge drinking, sleep difficulties, and sleep duration were studied across the LTPA trajectories with the 2011 data. The Bolck-Croon-Hagenaars (BCH) approach was utilized for this purpose [46–48]. In the BCH approach, the model estimates for the latent classes (i.e., LTPA trajectories) are not affected by the auxiliary variables (i.e., diet, screen time, smoking, binge drinking, sleep difficulties, and sleep duration), thereby preventing changes in LTPA trajectory class membership [48]. BCH weights were saved from the latent profile analysis run with the previously identified optimal number of LTPA trajectories. BCH weights are group-specific weights computed for each participant during the latent profile model estimation. BCH weights were used as training data and a multiple group regression model was estimated.

In the first step (model 1), the mean values of the health-related behaviors studied across the LTPA trajectory classes were unadjusted. To interpret mean differences required a Wald test p-value of <.05. In the second step (model 2), the mean values of the health-related behaviors were adjusted for age, BMI, education level and marital status. Model 2 was also adjusted for total energy intake when studying the mean diet index across the LTPA trajectories. In the third step (model 3), the mean values of the health-related behaviors were additionally adjusted with those of the previous corresponding health-related behaviors. When adjusting models 2 and 3, the mean values of the health behaviors were regressed on the above-mentioned covariates for the distinct LTPA trajectories. Differences in the regression intercepts (i.e., adjusted means of the health-related behaviors) were studied across the trajectory classes. Models were adjusted using standardized values of the covariates.

Cohen's d [49] and Cohen's h [50] were calculated for providing measure of effect concerning the mean differences of the health-related behaviors across the LTPA trajectory classes. Effect sizes were interpreted as small (≥0.20), medium (≥0.50), and large (≥0.80). Cohen's d measures the difference between two means divided by a standard deviation and Cohen's h is a measure of distance between two proportions [49, 50]. Cohen's d was calculated by using variances from the unadjusted models and intercepts (means) from the adjusted models 2 and 3. Cohen's h was calculated for probabilities of following sleep recommendations across the LTPA trajectory classes from the adjusted models 2 and 3.

The sample sizes dropped, especially in model 3. To verify the robustness of the models, sensitivity analyses were performed. Unadjusted analyses were performed for the same sample as in model 3 and then compared to the original results of model 1. The results of the sensitivity analyses closely resembled those of the main analyses. The main differences were in the associations between the LTPA trajectories and sleep difficulties in women: two additional significant associations were

Table 1 Descriptive statistics of the study sample and baseline LTPA in 1980

	Women ($N = 1813$)		Men ($N = 1740$)		
	Mean (SD) / %	***n***	**Mean (SD) / %**	***n***	***p*** [a]
LTPA in 1980 (index value, range 5–14)	8.6 (1.6)	1200	9.5 (1.9)	1151	< 0.001
LTPA in 2011 (index value, range 5–15)	9.1 (1.9)	1072	8.9 (1.9)	852	0.016
Body mass index in 2011 (kg/m2)	26.1 (5.5)	1118	27.0 (4.4)	931	< 0.001
Total energy intake in 2011 (kcal / day)	2090.0 (602.9)	998	2623.8 (775.6)	734	< 0.001
Education in 2011 (years)	15.7 (3.4)	1101	14.9 (3.8)	884	< 0.001
Marital status in 2011:					
Married / in registered relationship / cohabiting	77.5%	860	79.9%	712	
Unmarried / divorced / separated / widowed	22.5%	249	20.1%	179	
Healthy diet index in 1989 (range 9–54)	36.1 (4.4)	1349	34.4 (4.6)	1078	< 0.001
Healthy diet index in 2011 (range 0–27)	14.9 (4.0)	1014	11.9 (4.0)	747	< 0.001
Screen time during leisure in 2001 (h / day)	1.9 (1.2)	1353	2.2 (1.4)	1096	< 0.001
Screen time during leisure in 2011 (h / day)	2.7 (1.5)	1095	3.1 (1.7)	875	< 0.001
Smoking status in 1989 (range 1-4)	2.0 (1.2)	1471	2.2 (1.3)	1234	< 0.001
Non-smoker	50.4%	742	48.1%	594	
Former smoker	20.8%	306	14.3%	177	
Occasional smoker	6.5%	96	6.7%	83	
Regular smoker	22.2%	327	30.8%	380	
Smoking status in 2011 (range 1-4)	1.8 (1.1)	1110	2.0 (1.2)	889	< 0.001
Non-smoker	55.9%	621	44.7%	397	
Former smoker	24.6%	273	28.9%	257	
Occasional smoker	3.7%	41	5.2%	46	
Regular smoker	15.8%	175	21.3%	189	
Occasions of binge drinking in 1989 (range 1-5)	2.6 (1.6)	1437	2.9 (1.7)	1217	< 0.001
None	40.3%	579	39.6%	482	
One time	9.0%	129	5.8%	70	
Two to three times	17.9%	257	10.5%	128	
Four to ten times	15.4%	221	12.6%	153	
More than 10 occasions	17.5%	251	31.6%	384	
Binge drinking in 2011 (consumed > 6 drinks on one occasion; range 1-4)	1.4 (0.7)	1099	1.9 (1.0)	877	< 0.001
Six times a year or less	75.3%	827	48.0%	421	
One to three times a month	16.7%	184	27.9%	245	
Once a week	4.5%	49	14.4%	126	
Twice a week or more often	3.5%	39	9.7%	85	
Feeling fatigue in 1986 (range 1-4) [b]	2.8 (0.9)	691	2.4 (1.0)	554	< 0.001
Rarely or never	10.0%	69	23.5%	130	
Once a month	27.4%	189	29.2%	162	
Once a week	40.5%	280	35.0%	194	
Daily	22.1%	153	12.3%	68	
Sleep difficulties in 2011 (range 1-3)	1.7 (0.8)	1112	1.5 (0.7)	894	< 0.001
No sleep difficulty	51.4%	572	61.4%	549	
Moderate sleep difficulty	28.4%	316	24.8%	222	
Severe sleep difficulty	20.1%	224	13.8%	123	

Table 1 Descriptive statistics of the study sample and baseline LTPA in 1980 *(Continued)*

	Women (N = 1813)		Men (N = 1740)		
	Mean (SD) / %	n	Mean (SD) / %	n	p [a]
Sleeping time in 1986 (h/night)[b]	7.8 (0.9)	694	7.7 (0.9)	559	0.082
Less than seven hours per night	5.8%	40	8.6%	48	
Recommended 7–9 h per night	90.6%	629	89.1%	498	
More than nine hours per night	3.6%	25	2.3%	13	
Sleeping time in 2011 (h/night)	7.4 (1.0)	1111	7.1 (0.9)	892	< 0.001
Less than seven hours per night	18.8%	209	27.7%	247	
Recommended 7–9 h per night	78.4%	871	71.3%	636	
More than nine hours per night	2.8%	31	1.0%	9	

SD standard deviation; *LTPA* leisure-time physical activity. [a] *p*-value for sex difference (t-test). [b] Assessed only from the 18, 21 and 24 year-old participants

observed ($p < 0.05$). In 1986, the sleep difficulties variables were only assessed in the three oldest age cohorts. Thus, sleep difficulties in women were assessed at a higher mean age in model 3 than in model 1. However, model 3 was considered to be adequately reliable as it included all the available data with the relevant adjustments.

Quality assessment
To enhance reporting quality, this study was conducted according to extension of the Strengthening the Reporting of Observational Studies in Epidemiology guidelines for nutritional epidemiology (STROBE-nut) [51] [Supplementary file 3]. The Guidelines for Reporting on Latent Trajectory Studies (GRoLTS) checklist [52] was applied to enhance the quality of the latent profile analyses used (see previous study [22]).

Results
Participants and their characteristics
The sample size of the study was 3553 (51% females). All eight LTPA measurements had been completed by 4% of the participants, seven by 8%, six by 16%, five by 23%, four by 18%, three by 15%, two by 10% and one by 6%. Descriptive information on the participants is shown in Table 1.

Life-course leisure-time physical activity trajectories
Four similar LTPA trajectories were identified for both men and women from childhood to adulthood: persistently low-active, decreasingly active, increasingly active, and persistently active (Fig. 1a and b). An additional trajectory labeled inactivity was identified in women (Fig. 1b). The selection of the final number of trajectory classes has previously been reported in detail [22]. While the present trajectories were the same in shape and number as those previously identified, membership of the persistently low-active and decreasingly active trajectories had increased by 0.1% in males. More detailed description of the shapes of the trajectories can be found in the supplementary material [Supplementary file 1].

Adulthood health-related behaviors across the leisure-time physical activity trajectories
Dietary behavior
After all adjustments, the highest mean values of the diet index (range 0–27) were observed in the increasingly active (mean 16.8) and the lowest in the persistently inactive trajectory (12.6) among women while men in the persistently active trajectory had the highest mean values (13.0) and men in the persistently low-active one the lowest (10.7) (Fig. 2a, model 3). Women in the persistently inactive trajectory group had an unhealthier diet in adulthood than those in the other trajectory groups (Fig. 2a, models 1–3). The effect sizes were large between the persistently inactive and increasingly active and, also, the persistently inactive and active women. All effect sizes (Cohen's d and h) can be found in the supplementary material [Supplementary file 4]. The increasingly active women additionally had a healthier diet than their persistently low-active and decreasingly active peers. The persistently active women had a higher mean diet index than their low-active and decreasingly active peers (models 1–2), but these associations were attenuated after adjustment for previous dietary behavior (model 3). Among men, those in the persistently low-active trajectory had a lower mean diet index than their persistently and increasingly active peers (Fig. 2a, models 1–3). The decreasingly active men had an unhealthier diet than peers in the increasingly and persistently active trajectories (model 1) and a healthier diet than the persistently low-active men (model 2); however, these significant associations disappeared after full adjustments (model 3).

Screen time
After fully adjusting the models (Fig. 2b, model 3), the highest mean leisure screen time was observed among the persistently inactive women (mean 2.8 h / day) and

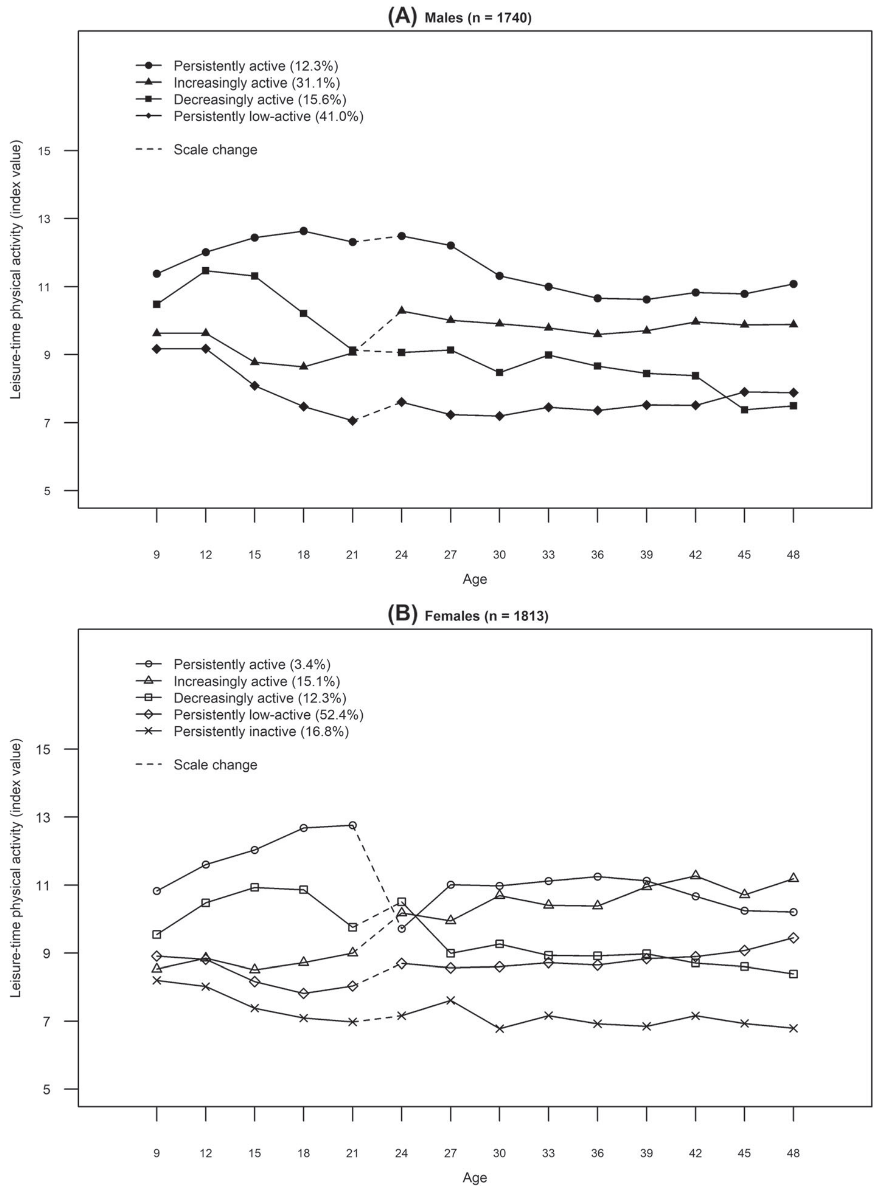

Fig. 1 Leisure-time physical activity trajectories for males (**a**) and females (**b**) (also published in [22, 24])

low-active men (3.5). The lowest mean leisure screen time was observed in the decreasingly active women (2.3) and the increasingly active men (2.6). Before adjustments, women in the inactive trajectory had higher leisure screen time than peers in the persistently, decreasingly and low-active trajectories (Fig. 2b, model 1). After adjustments, these significant associations disappeared. In contrast, mean differences in leisure screen time across the LTPA trajectories in men remained after adjustments (Fig. 2b, models 1–3). Men in the increasingly active trajectory had lower mean leisure screen time than their persistently low-active and persistently active peers.

Smoking

The mean values of smoking (range 1–4) were highest in the persistently inactive and low-active women (mean 1.9) and the persistently low-active men (2.2) whereas the increasingly active women and men had the lowest mean values of smoking (1.5 and 1.7, respectively) after full adjustments (Fig. 2c, model 3). The persistently inactive and low-active women were more frequently

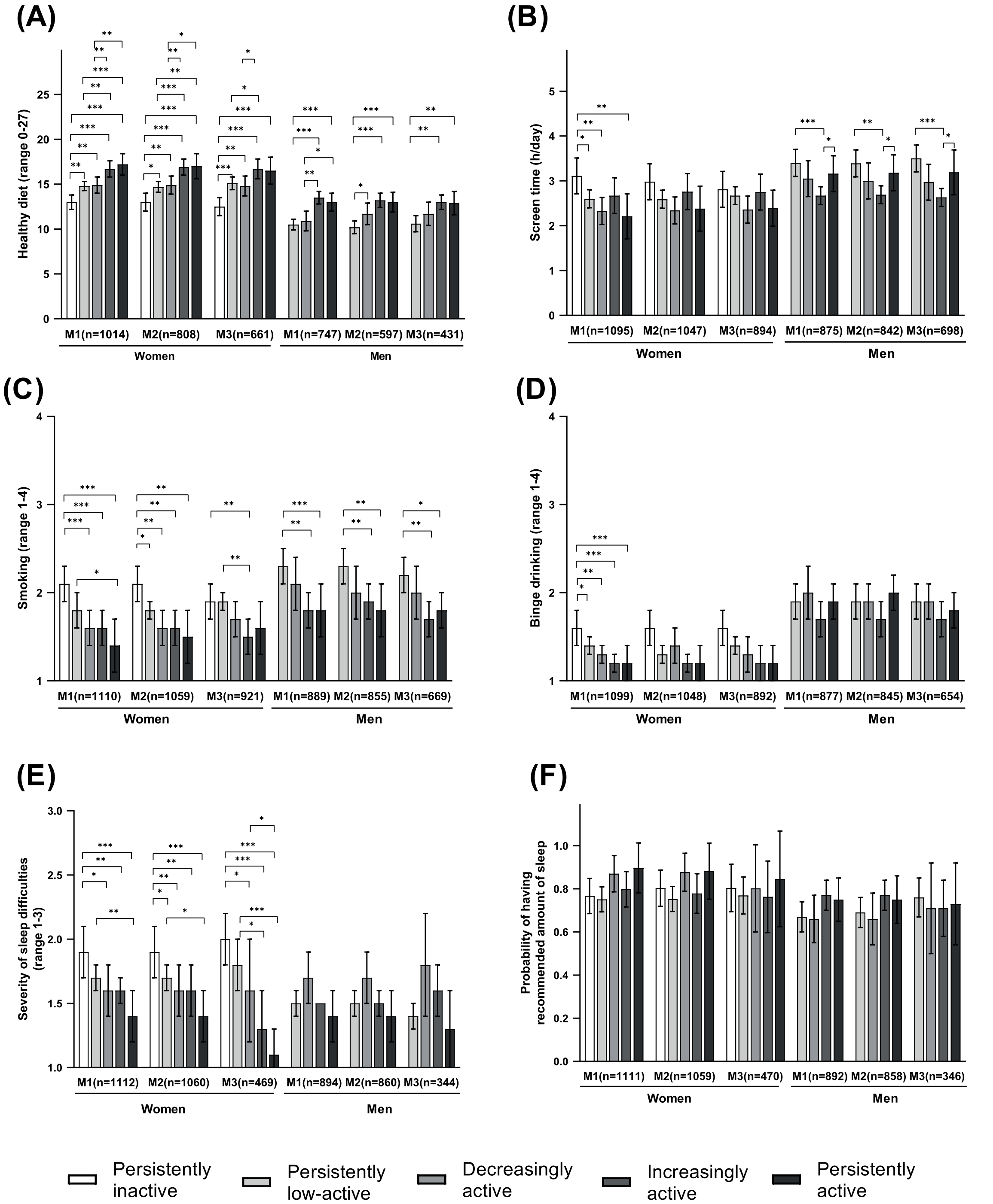

Fig. 2 Mean values and 95% confidence intervals for each health behavior (**a** = healthy diet; **b** = screen time; **c** = smoking; **d** = binge drinking; **e** = severity of sleep difficulties; **f** = probability of having recommended amount of sleep) across the leisure-time physical activity trajectories in the unadjusted model (M1) and adjusted models (M2 and M3) among women and men aged 33 to 49 years. M2 was adjusted for age, BMI, education, and marital status and diet additionally adjusted for total energy intake. In M3, each behavior was additionally adjusted for the corresponding earlier behavior: diet assessed in 1989, screen time in 2001, binge drinking in 1989, smoking in 1989, fatigue in 1986 and sleep duration in 1986. Significant mean differences in each health behavior across the LTPA trajectory classes in each model (M1–3) are marked with an asterisk (* = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$)

regular smokers than their increasingly active peers. Similarly, the persistently low-active men smoked more frequently than their persistently active and increasingly active peers (Fig. 2c, models 1–3).

Binge drinking

The mean values of binge drinking (range 1–4) were highest among the persistently inactive women (mean 1.6), and persistently low-active (1.9) and decreasingly active (1.9) men. The lowest mean values of binge drinking were observed in the increasingly and persistently active women (1.2) and increasingly active men (1.7) (Fig. 2d, model 3). The unadjusted analyses showed that the persistently inactive women were more frequently binge drinkers than the women in the other trajectories (Fig. 2d, model 1). After adjustments, no differences in binge drinking were found across the LTPA trajectory groups in women nor in men (Fig. 2d).

Sleep difficulties and sleep duration

The mean value of sleep difficulties (range 1–3) was highest in the persistently inactive trajectory of women (mean 2.0) and decreasingly active trajectory for men (1.8) while the persistently active women and men had the lowest mean values: 1.1 and 1.3, respectively (Fig. 2e, model 3). Significant mean differences in sleep difficulties between the LTPA trajectories were observed for women, but not for men (Fig. 2e). The persistently inactive women reported more sleep difficulties than their persistently, increasingly and decreasingly active peers. Moreover, the low-active women reported more sleep difficulties than their persistently (models 1–3) and increasingly active peers (model 3). No differences in the probability of having the recommended 7–9 h of sleep was observed between the LTPA groups in either gender (Fig. 2f, models 1–3).

Discussion

This study examined how diverse pathways (i.e., trajectories) of LTPA from childhood to adulthood were associated with diet, screen time, smoking, binge drinking, sleep difficulties and sleep duration in adulthood in men and women. Higher LTPA was associated with non-smoking and following a healthier diet in both genders and with less frequent sleep difficulties in women. Men whose LTPA increased in young adulthood reported lower screen time than persistently active and low-active men. Thus, those in the persistently, and especially increasingly active, life-course trajectories had accumulated several health-enhancing behaviors. Simultaneously, those in the inactive or low-active life-course trajectories had accumulated health-compromising behaviors. This is a concern from the public health perspective, as the biggest proportion of participants, of both sexes, were in the low-active trajectories. Our results are supported by previous cross-sectional [2, 53] and longitudinal [54, 55] findings showing a clustering of health behaviors at both ends of the lifestyle spectrum: the healthy and unhealthy. Previous findings show the phenomenon being more evident in women than men [38] which was observed also in the current study with generally higher effect sizes observed in women.

The poorest diet was found in the inactive trajectory for women and the low-active trajectory for men. This supports our previous findings [22] and those of another study showing that PA and fruit and vegetable consumption, an indicator of a healthy diet, are accumulated by the same individuals [53]. Of the studied behaviors, dietary behavior in adulthood – especially in women – showed the strongest association with the life-course LTPA trajectories. Several possible mechanisms behind the association have been proposed. For example, positive experiences from exercising may improve self-esteem [56], and body-image [57], and lead to promote individuals' self-efficacy and motivation to modify dietary habits as well [58–60]. Also, the similar barriers and motivators experienced for these two behaviors could explain the strong association. A study by Ashton et al. [61] showed that, in young men, motivators for PA and healthy eating were improving physical health, performance and physical appearance while logistic barriers (cost and access) and social factors (e.g., peer influence) were found as barriers for these two behaviours. Generally, women perceive healthy eating as more important [62, 63], experience a higher need for weight control [62], and are more health conscious [64] than men which could explain why the associations between LTPA and diet were stronger in women.

The strongest associations between LTPA trajectories and sleep difficulties were detected in the fully adjusted model for women that included only the three oldest age cohorts (42–49-year-old participants). Sleep difficulties were less prevalent among the increasingly and persistently active women than among their persistently low-active and inactive peers, while no associations were found among men. Generally, poor sleep quality is more prevalent among women than men [65]. In our sample, only 14% of men and up to 20% of women reported severe sleep difficulties in their forties. One explanation for the sex difference is probably the menopausal transition which is related to adverse changes in sleep quality [66, 67]. Previous studies on older adults have reported higher PA to be associated with maintenance of sleep sufficiency [68], lower probability of daytime sleepiness [69], and less sleep difficulties [18]. Among middle-aged adults, the findings are contradictory, some studies reporting an inverse [18, 68] and others no association between PA and sleep quality [69]. When studying adolescents, thus younger populations, no associations between PA trajectories and sleep time were found [70]. These age group-specific associations might reflect the aging-related decline in sleep quality [71] and, on the other hand, the importance of being physically active while ageing as it may improve sleep quality. Older age and female gender [69] both seemed to explain the associations we found between LTPA trajectories and sleep difficulties.

Several studies have reported an inverse association between PA and smoking: for example, smoking [72] and nicotine dependency [73] predicted lower levels of PA. Conversely, inactivity or occasional activity in adolescence predicted a higher prevalence of daily smoking in young adulthood [19]. Both our previous [23, 24] and current results corroborate those findings: LTPA development was inversely associated with smoking in adulthood for both genders – though not as strongly as it was with dietary behavior. Possible explanations for this include the clustering of positive and negative behaviors, and various psychological (e.g., depression), sociodemographic (e.g., education level), or physiological (e.g., lung capacity) factors [74]. Also, people who are physically active usually value physical fitness and strength [75], and are aware that smoking weakens the possibility to improve them.

Somewhat unexpectedly, not only the persistently low-active but also the persistently active men reported higher leisure screen time than their increasingly active counterparts. Earlier studies have found that men watch more sport on television [76], engage more in video gaming [77] and are more sensation-seeking (i.e., willing to engage in novel and intense activities) [78] than women. The persistently active trajectory might include a selected group of men seeking intense activities via participating in sports, viewing sports and playing e-sports or other video games. After full adjustments, no associations between LTPA trajectories and screen time in women were observed. Similarly, LTPA trajectories were not associated with sleeping duration nor binge drinking in either gender which differed from previous findings [18, 20].

The strengths of the current longitudinal study were its six age cohorts and several measurement points during a follow-up of over 30 years, enabling the study of the associations between life-course LTPA trajectories and several other health behaviors in adulthood. In this study, we expanded our previous research on health behaviors by including sleeping behavior, using an overall healthy diet index instead of measuring only fruit and vegetable consumption, and adding screen time to television viewing as sedentary behavior. Finally, instead of regular alcohol consumption we studied binge drinking, since this has been found to have marked effects on cardiovascular disease morbidity and mortality [79].

The study had its limitations. The use of self-reports may bias the results and lead to under- and over-reporting [80–82]. The proportion of women identified in the persistently active trajectory was small (3.4%): the association between persistent lifelong LTPA and other health behaviors among women should be confirmed in future studies. The measure of screen time did not include the use of electronic mobile devices such as smart phones or tablet computers and therefore does not cover all aspects of screen time. The models were adjusted for previous corresponding behaviors in order to ascertain whether the association between LTPA and a behavior is predicted by LTPA or by the behavior itself. This led to a lower sample size in the fully adjusted models which is why sensitivity analyses were performed in order to detect potential selection bias. Additionally, previous sleeping behavior in 1986 was assessed only from the three oldest age cohorts leading to a selection of older sample when compared to the other fully adjusted models. Moreover, if the study question concerning binge drinking had been phrased separately for both genders allowing the use of a lower threshold value for women, a bigger proportion of women might have been defined as binge drinkers. Even though several covariates were used, the associations may also be affected by unmeasured confounders (e.g., chronic diseases [83, 84], mental health issues [85], temperament [86], transitions and life events [87], social support [88], or occupational status [87]). Conclusions on causality may be biased, as observational studies can include reverse causation. The study sample presents a Finnish population, and therefore, the results are not necessarily generalizable to other populations with, for example, a different socio-economic or ethnic background. Finally, researchers and readers need to acknowledge that trajectory group membership is not certain [89] as it only presents the probability of the participant to follow a trajectory.

In past studies, the previous PA level has been found to predict the future PA level [42, 90]. The current study adds to those findings by highlighting the importance of managing to increase LTPA during the life-course as not only persistent but also increasing activity was associated with several healthy behaviors in adulthood. This is an encouraging message for health promotion: the LTPA level in childhood and adolescence does not necessarily determine the LTPA level later in life, and LTPA initiated even after adolescence may play a role in adoption to other health-promoting behaviors in adulthood. These results may be leveraged as a platform for trajectory group-specific PA counseling with potential ramifications for additional healthy lifestyle choices. Our results also generate hypotheses for future qualitative research on the reasons underlying LTPA behavior, and for intervention studies to ascertain the causal relations behind these associations. Moreover, the constantly developing objective measurements enable collecting data on how PA, sedentary behavior, and sleeping integrate across the whole day (see e.g. [91]). Studies using accelerometers can provide a more comprehensive understanding of the codependency of these so-called time-use behaviors. Future longitudinal studies could identify trajectories/profiles of 24-h time-use behaviors (see e.g. [92]) and study their associations with other lifestyle choices.

Conclusions

The present findings underline the different associations between life-course LTPA trajectories and various other health-related behaviors in adulthood and the sex differences in these associations. While the findings corroborated previous findings on the accumulation of healthy behaviors with persistent activity and of unhealthy behaviors with persistent inactivity and low activity, they also highlighted the meaning of increase in LTPA level. Especially, the study offered insight into the association between persistent LTPA during life-course and increased LTPA after childhood or adolescence with healthy eating and non-smoking in both genders and having less sleep difficulties in middle-aged women. The results suggest that to be physically active in adulthood does not necessarily require the initiation of a physically active lifestyle already in childhood. Promoting LTPA at all ages is important, not only because it may increase the level of PA, but because of its potential associations with healthy lifestyle choices later in life.

Abbreviations

BCH: Bolck-Croon-Hagenaars approach; BMI: Body mass index; ES: Effect size; LTPA: Leisure-time physical activity; PA: Physical activity; YFS: The Cardiovascular Risk in Young Finns Study

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12889-021-10554-w.

Additional file 1: Supplementary file 1. Statistical analyses used for identifying the leisure-time physical activity trajectories and the description of the trajectories.

Additional file 2: Supplementary file 2. Description of the covariates.

Additional file 3: Supplementary file 3. STROBE-nut checklist.

Additional file 4: Supplementary file 4. Effect sizes (Cohen's d and h) corresponding to adjusted models two and three for both genders.

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Authors' contributions

IL, MH, SP, KS, THT, AT, MF, SR and KP made substantial contributions to the conception and design of the study. AT provided statistical expertise, and NH-K participated in the acquisition of the data. IL, MH, AT, SP, KS, MF, KP, SR, OR and THT interpreted the data. IL wrote the manuscript. OR was responsible for the administration of the YFS. All authors (IL, MH, AT, SP, KS, MF, KP, SR, XY, NH-K, OR and THT) critically revised and edited the work and read and approved the final manuscript. All authors agreed both to be personally accountable for their own contributions and to ensure that questions related to the accuracy or integrity of any part of the work, even parts in which the author was not personally involved, were appropriately investigated, resolved, and the resolution documented in the literature.

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Availability of data and materials

The datasets analyzed in this study are not publicly available for ethical and legal reasons but are available from the Publication Committee of the YFS on reasonable request. For more information on requests related to dataset access, please contact Professor Olli Raitakari, Project Director of the YFS, University of Turku, Finland, olli.raitakari@utu.fi.

Declarations

Ethics approval and consent to participate

The study protocol was reviewed and approved by the Ethics Committee of the Hospital District of Southwest Finland in order to obtain and access data. A written informed consent for participation in the study was obtained from all participants (or their parents / guardian with children under 16 years of age) in accordance with the Helsinki Declaration [27].

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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Publisher's Note

Supplementary file 1. Statistical analyses used for identifying the leisure-time physical activity trajectories and the description of the trajectories.

Statistical analyses used to identify leisure-time physical activity trajectories

Latent variable mixture modeling is a person-centered statistical tool that enables researchers to study similarities and differences between individuals in a data-driven manner [1–3]. The goal is to probabilistically assign study participants into subgroups by inferring each individual's membership to latent classes [2]. In the current study, self-reported leisure-time physical activity (LTPA) subgroups were studied. Participants with at least one measurement of LTPA were included. The modeling enables including participants with only one measurement since the participant will have his/her own probabilities calculated for his/her membership in all of the latent classes estimated [2].

Latent profile analysis, a type of mixture modelling, was conducted separately for males and females to identify distinct LTPA trajectories from childhood to adulthood. Before modelling commenced, the longitudinal data were rearranged so that time points referred to ages instead of measurement years. Because the content of the LTPA questionnaires changed in 1992, overlapping items were recoded for missing values. After recoding, the LTPA questionnaires were similar in content from age 9 to 21 and from age 24 to 48. The latent profile analysis was based on the means of the LTPA outcome measures from age 9 to 48, and error variances were assumed to be equal across classes.

Models with one to six LTPA classes were fitted. Statistical criteria for the goodness-of-fit of each model was used to decide the number of classes. The criteria evaluated in this study were Akaike's information criterion (AIC), the Bayesian information criterion (BIC) and the sample-size adjusted BIC (ABIC). For all three criteria, the lower the value, the better the fit of the model. In addition, the Vuong-Lo-Mendell-Rubin likelihood ratio test (VLMR), Lo-Mendell-Rubin adjusted likelihood ratio test (LMR) and parametric bootstrapped likelihood ratio test (BLRT) statistical tests were used to determine the optimum number of classes. The estimated model was compared to the model with one class less, a lower *p*-value indicating that the model with one class less is rejected in favour of the estimated model [1]. Entropy values and the average posterior probabilities (AvePP) for most likely latent class membership were used to evaluate the quality of the classification. Both measures ranged from 0 to 1, with the value 1 indicating a perfect classification. Values higher than 0.7 were considered acceptable for the average posterior probabilities [4, 5]. Missing data were assumed to be missing at random (MAR). Model parameters were estimated by using the full information maximum likelihood (FIML) method with robust standard errors, thereby enabling use of all the available data.

Description of the leisure-time physical activity trajectories for males from childhood to adulthood

The following four LTPA trajectory classes were identified for males: persistently low-active (41 %), decreasingly active (16 %), increasingly active (31 %), and persistently active (12 %) (Figure 1A). At each additional step in the modelling, the ABIC continued to decrease and the *p*-value of the BLRT remained low (<.001) (see Table 2 in [6]). However, in the five-class solution, the AvePP value for one of the latent classes fell below the acceptable level (<0.7), the *p*-values of the VLMR and LMR were higher than 0.05 and the BIC started to rise again, hence the four-class solution was considered optimal.

Males on the persistently active trajectory remained the most active (mean LTPA index value 11.6) while those on the persistently low-active trajectory remained the least active almost throughout the study period (mean LTPA index value 7.8). Among the low-active participants, LTPA decreased considerably between ages 12 (mean LTPA index value 9.2; 95% CI 8.9-9.4) and 21 (mean LTPA index value 7.1; 95% CI 6.8-7.3). A decline in LTPA for those on the decreasingly active trajectory also begun around age 12 (mean LTPA index value 11.5; 95% CI 11.2-11.8), continuing until age 48 (mean LTPA index value 7.5; 95% CI 6.3-8.7) when dropping to the level of the low-active participants (mean LTPA index value 7.9; 95% CI 7.4-8.4). At age 18, the LTPA level of the increasers reached its lowest point (mean LTPA index value 8.6; 95% CI 8.3-9.0), and at the age of 24 its highest point (mean LTPA index value 10.3; 95% CI 9.5-11.1). After the age of 24, the increasingly active trajectory remained rather stable. Despite that the trajectory was stable in adulthood, the trajectory was labelled as the increasingly active trajectory since it differed in shape from the other trajectories by being the only one where an increasing tendency of LTPA was observed after childhood and adolescence (Figure 1A).

Description of the leisure-time physical activity trajectories for females from childhood to adulthood

The following five LTPA trajectory classes were identified for females: persistently inactive (17 %), persistently low-active (52 %), decreasingly active (12 %), increasingly active (15 %), and persistently active (3 %) (Figure 1B). The *p*-values of the VLMR and LMR were below 0.05 only up to the three-class solution. However, since the ABIC continued to decrease substantially and the *p*-value of the BLRT was lower than 0.001 in each additional step, the modelling was continued up to the six-class solution (see Table 2 in [6]). At the six-class solution, the AvePP fell below the acceptable level (<0.7) in two of the latent classes, and the BIC started to increase again; hence, the five-class solution was considered optimal.

Among females, the biggest changes in LTPA level occurred before age 27, after which it stabilized. The increasingly active trajectory was an exception, showing a continuously increasing trend from childhood to adulthood: the mean LTPA index value increased from 8.5 (95% CI: 8.1-9.0) to 11.2 (95% CI: 9.9-12.5) between ages 9 and 48. The increasers were the second least active participants at age 9, but around age 40 they became the most active, exceeding the LTPA level of the persistently active participants. For those on the decreasingly active trajectory, the decline in LTPA started at age 18 (LTPA index value 10.9; 95% CI: 9.6-12.1) and continued to the end of the follow-up at age 48 (LTPA index value 8.4; 95% CI: 7.3-9.5). The trajectory was labelled as the decreasingly active one since these participants were comparatively active in childhood and adolescence until their LTPA decreased into the level of the low-active participants in adulthood. A decrease in LTPA was also seen among those on the low-active trajectory from ages 9 (LTPA index value 8.9; 95% CI: 8.6-9.2) to 18 (LTPA index value 7.8; 95% CI: 7.6-8.1), with slight increase in mid-adulthood. However, this decrease was smaller than that of the decreasingly active females. The participants on the persistently inactive trajectory remained the least active, showing a slightly decreasing tendency in LTPA across the study period (mean LTPA index value 7.2) (Figure 1B).

Abbreviations

ABIC: Adjusted Bayesian information criterion

AIC: Akaike's information criterion

AvePP: Average posterior probabilities

BIC: Bayesian information criterion CI: Confidence interval

BLRT: Parametric bootstrapped likelihood ratio test

LMR: Lo-Mendell-Rubin adjusted likelihood ratio test

LTPA: Leisure-time physical activity

VLMR: Vuong-Lo-Mendell-Rubin likelihood ratio test

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Supplementary file 2. Description of the covariates.

Age, body mass index (BMI), level of education and marital status were elicited in 2011 and used as covariates. Weight was measured with a digital scale and height with wall-mounted stadiometer. BMI was calculated as kg/m^2. Self-reported number of years of education was used as a proxy for socioeconomic status. Marital status was dichotomized: 1=unmarried, divorced, legally separated or widowed, and 2=married, in a registered relationship or cohabiting. Total energy intake was assessed based on the food frequency questionnaire in 2011 [4] and used as a covariate for dietary behavior in the analyses.

In addition, health behaviors in childhood, adolescence or young adulthood were used as covariates for the corresponding outcome health behaviors in adulthood. A healthy diet index was created from the 1989 data, with food items differing slightly from those in the 2011 index as the questionnaire had been modified and improved during the intervening years. Food items defined as healthy were fruits, vegetables, fish, and vegetable fats; unhealthy items were sausage dishes, sugared beverages, sweets, pastry and ice cream. Consumption frequencies of different food items per month were assessed on a scale from 1 to 6. For the healthy foods, 6=daily consumption of the item and 1=never or nearly never. For the unhealthy foods, the scale was reversed. The points were summed to create an index ranging from 9 to 54, with higher values indicating a healthier diet.

Finally, the following variables were used as covariates when studying the associations between the corresponding adulthood behaviors and LTPA trajectories: screen time assessed in 2001 (television and computer time in hours per day), smoking in 1989 (scale from 1=non-smoker to 4=regular smoker), total of binge drinking occasions in 1989 (scale from 1=none to 5=over 10 occasions), meeting the sleep recommendations (7-9 hours of sleep/night) in 1986 and feeling fatigue (scale from 1=rarely/never to 4=daily) in 1986. The participants were aged

12-27 years in 1989 and 24-39 years in 2001. Sleep duration and fatigue were assessed from a subsample of the 18-, 21- and 24-year-old participants in 1986.

The year 1989 was the first follow-up year when smoking and alcohol consumption were queried from all six age cohorts in the Cardiovascular Risk in Young Finns Study. In order to use as big sample as possible, data collected in 1989 concerning previous smoking and binge drinking was used. Also, data on dietary behavior was collected in 1989 and therefore was used as covariate. Screen time and sleeping were not queried in 1989. Screen time was queried in year 2001 for the first time and sleeping behavior in 1986 from a subsample and then again in 2001, 2007 and 2011 from the whole study sample. This is why data concerning previous sleeping behavior was from the year 1986 and screen time from 2001.

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Supplementary file 3. STROBE-nut: An extension of the STROBE statement for nutritional epidemiology

Lachat C et al. (2016) STrengthening the Reporting of OBservational studies in Epidemiology – Nutritional Epidemiology (STROBE-nut): an extension of the STROBE statement. Plos Medicine 13(6) http://dx.doi.org/10.1371/journal.pmed.1002036 pdf or online version.

Item	Item nr	STROBE recommendations	Extension for Nutritional Epidemiology studies (STROBE-nut)	Reported (x=yes; -=no)
Title and abstract	1	(a) Indicate the study's design with a commonly used term in the title or the abstract. (b) Provide in the abstract an informative and balanced summary of what was done and what was found.	**nut-1** State the dietary/nutritional assessment method(s) used in the title, abstract, or keywords.	1a) x 1b) x nut-1) x
Introduction				
Background rationale	2	Explain the scientific background and rationale for the investigation being reported.		2) x
Objectives	3	State specific objectives, including any pre-specified hypotheses.		3) x
Methods				
Study design	4	Present key elements of study design early in the paper.		4) x

Item	Item nr	STROBE recommendations	Extension for Nutritional Epidemiology studies (STROBE-nut)	Reported (x=yes; -=no)
Settings	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection.	**nut-5** Describe any characteristics of the study settings that might affect the dietary intake or nutritional status of the participants, if applicable.	5) x nut-5) -
Participants	6	a) Cohort study—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up. Case-control study—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls. Cross-sectional study—Give the eligibility criteria, and the sources and methods of selection of participants. (b) Cohort study—For matched studies, give matching criteria and number of exposed and unexposed. Case-control study—For matched studies, give matching criteria and the number of controls per case.	**nut-6** Report particular dietary, physiological or nutritional characteristics that were considered when selecting the target population.	6a) x 6b) - nut-6) x

Item	Item nr	STROBE recommendations	Extension for Nutritional Epidemiology studies (STROBE-nut)	Reported (x=yes; -=no)
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable.	**nut-7.1** Clearly define foods, food groups, nutrients, or other food components. **nut-7.2** When using dietary patterns or indices, describe the methods to obtain them and their nutritional properties.	7) x, Table 1, Supplementary file 2 nut-7.1) x, Supplementary file 2 nut-7.2) x, Supplementary file 2
Data sources - measurements	8	For each variable of interest, give sources of data and details of methods of assessment (measurement).Describe comparability of assessment methods if there is more than one group.	**nut-8.1** Describe the dietary assessment method(s), e.g., portion size estimation, number of days and items recorded, how it was developed and administered, and how quality was assured. Report if and how supplement intake was assessed. **nut-8.2** Describe and justify food composition data used. Explain the procedure to match food composition with consumption data. Describe the use of conversion factors, if applicable. **nut-8.3** Describe the nutrient requirements, recommendations, or dietary guidelines and the evaluation	8) x, Supplementary files 1 and 2 nut-8.1) x nut-8.2) - nut-8.3) - nut-8.4) - nut-8.5) - nut-8.6) x

Item	Item nr	STROBE recommendations	Extension for Nutritional Epidemiology studies (STROBE-nut)	Reported (x=yes; -=no)
			approach used to compare intake with the dietary reference values, if applicable. **nut-8.4** When using nutritional biomarkers, additionally use the STROBE Extension for Molecular Epidemiology (STROBE-ME). Report the type of biomarkers used and their usefulness as dietary exposure markers. **nut-8.5** Describe the assessment of nondietary data (e.g., nutritional status and influencing factors) and timing of the assessment of these variables in relation to dietary assessment. **nut-8.6** Report on the validity of the dietary or nutritional assessment methods and any internal or external validation used in the study, if applicable.	
Bias	9	Describe any efforts to address potential sources of bias.	**nut-9** Report how bias in dietary or nutritional assessment was addressed, e.g., misreporting, changes in habits as a result of being measured, or data imputation from other sources	9) x nut-9.1) -
Study Size	10	Explain how the study size was arrived at.		10) x

Item	Item nr	STROBE recommendations	Extension for Nutritional Epidemiology studies (STROBE-nut)	Reported (x=yes; -=no)
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why.	**nut-11** Explain categorization of dietary/nutritional data (e.g., use of N-tiles and handling of nonconsumers) and the choice of reference category, if applicable.	11) x, Supplementary files 1 and 2 nut-11) -
Statistical Methods	12	(a) Describe all statistical methods, including those used to control for confounding (b) Describe any methods used to examine subgroups and interactions. (c) Explain how missing data were addressed. (d) Cohort study—If applicable, explain how loss to follow-up was addressed. Case-control study—If applicable, explain how matching of cases and controls was addressed. Cross-sectional study—If applicable, describe analytical methods taking account of sampling strategy. (e) Describe any sensitivity analyses.	**nut-12.1** Describe any statistical method used to combine dietary or nutritional data, if applicable. **nut-12.2** Describe and justify the method for energy adjustments, intake modeling, and use of weighting factors, if applicable. **nut-12.3** Report any adjustments for measurement error, i.e,. from a validity or calibration study.	12a) x, Supplementary file 1 12b) x, Supplementary file 1 12c) x 12d) x 12e) x nut-12.1) x nut-12.2) Supplementary file 2 nut-12.3) -

Item	Item nr	STROBE recommendations	Extension for Nutritional Epidemiology studies (STROBE-nut)	Reported (x=yes; -=no)
Results				
Participants	13	(a) Report the numbers of individuals at each stage of the study—e.g., numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analyzed. (b) Give reasons for non-participation at each stage. (c) Consider use of a flow diagram.	**nut-13** Report the number of individuals excluded based on missing, incomplete or implausible dietary/nutritional data.	13a) x, figures 1 and 2 13b) x 13c) - nut-13) Figure 2
Descriptive data	14	(a) Give characteristics of study participants (e.g., demographic, clinical, social) and information on exposures and potential confounders (b) Indicate the number of participants with missing data for each variable of interest (c) Cohort study—Summarize follow-up time (e.g., average and total amount)	**nut-14** Give the distribution of participant characteristics across the exposure variables if applicable. Specify if food consumption of total population or consumers only were used to obtain results.	14a) Table 1 14b) Figure 2 14c) x nut-14) Table 1
Outcome data	15	Cohort study—Report numbers of outcome events or summary measures over time.		15) x, Figure 2, Supplementary file 4

Item	Item nr	STROBE recommendations	Extension for Nutritional Epidemiology studies (STROBE-nut)	Reported (x=yes; -=no)
		Case-control study—Report numbers in each exposure category, or summary measures of exposure. Cross-sectional study—Report numbers of outcome events or summary measures.		
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included. (b) Report category boundaries when continuous variables were categorized. (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period.	**nut-16** Specify if nutrient intakes are reported with or without inclusion of dietary supplement intake, if applicable.	16a) x, Figure 2, Supplementary file 4 16b) see Methods 16c) Supplementary file 1 nut-16) -
Other analyses	17	Report other analyses done—e.g., analyses of subgroups and interactions and sensitivity analyses.	**nut-17** Report any sensitivity analysis (e.g., exclusion of misreporters or outliers) and data imputation, if applicable.	17) x, Supplementary file 4 nut-17) x
Discussion				

Item	Item nr	STROBE recommendations	Extension for Nutritional Epidemiology studies (STROBE-nut)	Reported (x=yes; -=no)
Key results	18	Summarize key results with reference to study objectives.		18) x
Limitation	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias.	**nut-19** Describe the main limitations of the data sources and assessment methods used and implications for the interpretation of the findings.	19) x nut-19) x
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence.	**nut-20** Report the nutritional relevance of the findings, given the complexity of diet or nutrition as an exposure.	20) x nut-20) x
Generalizability	21	Discuss the generalizability (external validity) of the study results.		21) x
Other information				
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based.		22) x
Ethics			**nut-22.1** Describe the procedure for consent and study approval from ethics committee(s).	nut-22.1) x

Item	Item nr	STROBE recommendations	Extension for Nutritional Epidemiology studies (STROBE-nut)	Reported (x=yes; -=no)
Supplementary material		*There are 4 additional files as supplementary material.*	**nut-22.2** Provide data collection tools and data as online material or explain how they can be accessed.	nut-22.2) x

Supplementary file 4. Effect sizes (Cohen's d and h) corresponding to adjusted models two and three for both genders.

			Cohen's d										Cohen's h	
			Healthy diet		Screen time		Smoking		Binge drinking		Severity of sleep difficulties		Probability of having recommended amount of sleep	
			M2	M3	M2	M3	M2	M3	M2	M3	M2	M3	M2	M3
Comparison between LTPA trajectories, women:														
Persistently inactive	vs.	Persist. low-active	*0.44*	0.67	(0.27)	(0.07)	*0.25*	(0.00)	(0.37)	(0.25)	*0.24*	(0.24)	(0.12)	(0.09)
Persistently inactive	vs.	Decreasingly active	0.50	0.60	(0.41)	(0.23)	*0.43*	(0.17)	(0.24)	(0.36)	*0.38*	0.50	(0.20)	(0.01)
Persistently inactive	vs.	Increasingly active	**1.00**	**1.08**	(0.10)	(0.00)	*0.48*	*0.38*	(0.53)	(0.54)	*0.39*	**0.91**	(0.06)	(0.10)
Persistently inactive	vs.	Persistently active	**1.08**	**1.08**	(0.32)	(0.21)	0.50	(0.25)	(0.46)	(0.46)	0.64	**1.14**	(0.22)	(0.11)
Persist. low-active	vs.	Decreasingly active	(0.05)	(0.08)	(0.25)	(0.25)	(0.18)	(0.18)	(0.14)	(0.14)	(0.13)	(0.25)	(0.32)	(0.08)
Persist. low-active	vs.	Increasingly active	0.57	*0.41*	(0.14)	(0.07)	(0.19)	*0.38*	(0.15)	(0.30)	(0.13)	0.63	(0.06)	(0.01)
Persist. low-active	vs.	Persistently active	0.61	(0.37)	(0.16)	(0.24)	(0.27)	(0.27)	(0.14)	(0.28)	*0.37*	**0.87**	(0.34)	(0.20)
Decreasingly active	vs.	Increasingly active	0.52	0.50	(0.32)	(0.25)	(0.00)	(0.24)	(0.37)	(0.19)	(0.00)	(0.42)	(0.26)	(0.09)
Decreasingly active	vs.	Persistently active	0.59	(0.48)	(0.09)	(0.00)	(0.11)	(0.11)	(0.35)	(0.18)	(0.29)	**0.73**	(0.02)	(0.12)
Increasingly active	vs.	Persistently active	(0.03)	(0.05)	(0.23)	(0.23)	(0.13)	(0.13)	(0.00)	(0.00)	(0.29)	(0.29)	(0.28)	(0.21)
Comparison between LTPA trajectories, men:														
Persist. low-active	vs.	Decreasingly active	*0.40*	(0.29)	(0.21)	(0.26)	(0.22)	(0.14)	(0.08)	(0.01)	(0.24)	(0.56)	(0.06)	(0.11)
Persist. low-active	vs.	Increasingly active	**0.80**	0.64	*0.45*	0.55	*0.38*	*0.38*	(0.13)	(0.16)	(0.00)	(0.28)	(0.18)	(0.11)
Persist. low-active	vs.	Persistently active	0.76	0.60	(0.10)	(0.16)	*0.36*	*0.25*	(0.12)	(0.03)	(0.19)	(0.18)	(0.13)	(0.07)
Decreasingly active	vs.	Increasingly active	(0.40)	(0.35)	(0.24)	(0.29)	(0.14)	(0.24)	(0.22)	(0.18)	(0.24)	(0.30)	(0.24)	(0.00)
Decreasingly active	vs.	Persistently active	(0.37)	(0.31)	(0.12)	(0.11)	(0.15)	(0.12)	(0.04)	(0.04)	(0.41)	(0.72)	(0.20)	(0.04)
Increasingly active	vs.	Persistently active	(0.03)	(0.03)	*0.43*	*0.48*	(0.04)	(0.09)	(0.27)	(0.14)	(0.19)	(0.49)	(0.05)	(0.04)

Numbers in bold represent large magnitude of effect (≥0.80), underlined numbers represent medium magnitude of effect (≥0.50) and numbers in italic represent small magnitude of effect (≥0.20). The Cohen's d and h values are marked in parentheses if there was no significant difference observed between the mean values of the health-related behaviors across the LTPA trajectory classes.

M2 model 2; *M3* model 3; *LTPA* leisure-time physical activity; *vs.* versus; *Persist*. persistently