JYU DISSERTATIONS 790

Tuula Aira

Physical Activity Patterns from Adolescence to Young Adulthood

Their Characteristics and Relationship with Cardiometabolic Health

UNIVERSITY OF JYVÄSKYLÄ
FACULTY OF SPORT AND HEALTH SCIENCES

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Editors
Anne Viljanen
Faculty of Sport and Health Sciences, University of Jyväskylä
Timo Hautala
Open Science Centre, University of Jyväskylä

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ABSTRACT

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The decline in physical activity (PA) from adolescence to young adulthood is well established. However, while some groups of adolescents follow the general pattern of decreased activity, others increase or maintain high or low activity. The correlates of different longitudinal PA patterns may vary, as may the health outcomes, offering valuable information for targeted health promotion. This study examined how demographics, psychosocial factors, health behaviours, PA domains, and sedentary time are associated with longitudinal PA patterns from adolescence to young adulthood. It also explored the relations between PA patterns and the development in cardiometabolic risk factors.

The cohort study data consisted of 254 Finns participating in the *Diverging paths in physical activity and sports participation: Health Promoting Sports Club (HPSC) cohort study* at ages 15 and 19. The data were collected by questionnaires, accelerometry, and laboratory measurements, and a data-driven method was used to identify the longitudinal PA patterns.

There was large variation in PA development between ages 15 and 19. The PA patterns included two *decreasing PA* patterns, as well as *activity maintainers*, *inactivity maintainers*, and a small group of *PA increasers*. Sports club participation was associated with *maintained PA*, whereas sustained passive commuting was associated with *maintained inactivity*. Communication difficulties with one's father and lower fruit and vegetable consumption were related to *decreased PA from moderate to low* and *maintained inactivity*. Adolescents who decreased their activity *from moderate to low* also had a higher prevalence of smoking as young adults. Favourable blood pressure changes were found among *PA increasers*. Unfavourable changes in body mass index, insulin, glucose, and high-density lipoprotein cholesterol were found in groups with *decreasing PA*.

Decreasing PA is associated with unfavourable changes in cardiometabolic risk factors already in adolescence. Due to the large variation in PA development and related correlates, targeted health promotion is needed. Sports clubs have an important role in maintaining PA. Health promotion that does not directly involve PA (e.g. via support for open communication between adolescents and their fathers) may provide opportunities to promote PA.

Keywords: adolescence, cardiometabolic risk factors, health behaviour, physical activity, psychosocial factors, sports, young adults

TIIVISTELMÄ (ABSTRACT IN FINNISH)

Aira, Tuula
Liikkumisen muutos ja pysyvyys nuoruudesta nuoreen aikuisuuteen: selittävät tekijät ja yhteydet kardiometabolisiin riskitekijöihin
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Fyysinen aktiivisuus vähenee nuoruuden ja nuoren aikuisuuden välillä. Kaikkien liikkuminen ei kuitenkaan vähene, vaan osa nuorista säilyttää aktiivisuustasonsa ennallaan ja osa lisää liikkumistaan. Liikkumisen muutosta ja pysyvyyttä selittävät tekijät voivat olla erilaisia. Liikkumisen muutos saattaa heijastua myös sydän- ja verisuonisairauksien sekä tyypin 2 diabeteksen riskitekijöihin. Tutkimuksessa selvitettiin, miten terveyskäyttäytyminen, demografiset ja psykososiaaliset tekijät, liikkumisen muodot ja paikallaanolo ovat yhteydessä liikkumiskäyttäytymisen muutokseen (liikkumisen muutosryhmään kuulumiseen) ikävuosien 15 ja 19 välillä. Lisäksi tutkittiin kardiometabolisten riskitekijöiden kehittymistä liikkumisen muutosryhmissä.

Tutkimuksen aineisto muodostui 254 suomalaisen nuoren liikemittaustiedoista, kyselylomakevastauksista sekä laboratoriomittauksista, jotka kerättiin osana seurantatutkimusta nuorten ollessa 15 ja 19 vuoden ikäisiä. Liikkumisen muutosryhmät muodostettiin aineistolähtöisesti.

Aineistosta muodostui kaksi vähenevän aktiivisuuden ryhmää ja aiemman aktiivisuustasonsa säilyttävien ryhmät (aktiivisuuden säilyttäjät ja läpi nuoruuden vähän liikkuvat) sekä pieni liikkumista lisäävien joukko. Liikuntaseuraosallistuminen oli yhteydessä aktiivisuuden säilymiseen, kun taas passiivisesti kuljetut koulu-, opiskelu- ja työmatkat sekä nuorena että nuorena aikuisena olivat yleisempiä vähän liikkuvilla. Keskusteluvaikeudet isän kanssa sekä vähäisempi vihannesten ja hedelmien käyttö olivat yhteydessä vähäisenä säilyvään liikkumiseen sekä liikkumisen vähenemiseen alhaiselle tasolle. Jälkimmäisessä ryhmässä myös tupakointi nuorena aikuisena oli tyypillisempää. Liikkumisen lisääjien verenpaine laski seurannan aikana, kun taas painoindeksi, insuliini-, glukoosi- ja HDL-kolesterolipitoisuudet kehittyivät epäedulliseen suuntaan liikkumista vähentävissä ryhmissä.

Liikkumisen väheneminen on yhteydessä epäedullisiin muutoksiin kardiometabolisissa riskitekijöissä jo nuorena. Liikuntaseuraosallistuminen tukee aktiivisuuden säilymistä. Terveyden edistäminen, joka ei suoraan liity liikkumiseen, kuten isien ja nuorten vuorovaikutuksen tukeminen, tulisi nähdä mahdollisuutena edistää liikkumista.

Asiasanat: fyysinen aktiivisuus, liikuntaseurat, nuoret, nuoret aikuiset, riskitekijät, terveyskäyttäytyminen

Author	Tuula Aira, MSc Research Centre for Health Promotion Faculty of Sport and Health Sciences University of Jyväskylä Finland tuula.m.aira@jyu.fi ORCID 0000-0001-9770-1732
Supervisors	Professor Sami Kokko, PhD Research Centre for Health Promotion Faculty of Sport and Health Sciences University of Jyväskylä Finland Professor Tommi Vasankari, MD, PhD UKK Institute for Health Promotion Research & Faculty of Medicine and Health Technology Tampere University Finland
Reviewers	Professor Rochelle Eime, PhD School of Science, Psychology and Sport Federation University Australia Associate Professor Andrew Atkin, PhD School of Health Sciences Faculty of Medicine and Health Sciences University of East Anglia United Kingdom
Opponent	Professor Tiina Laatikainen, MD, PhD Institute of Public Health and Clinical Nutrition School of Medicine, Faculty of Health Sciences University of Eastern Finland & National Institute for Health and Welfare (THL) Finland

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My path as a researcher has not been entirely typical. I started as a project researcher in the Research Centre for Health Promotion, where I had the privilege of learning how to conduct research on several topics. However, the Diverging paths in physical activity and sports participation: Health Promoting Sports Club (HPSC) cohort study was the project that drew me in. The study began as a cross-sectional study, but continued as a follow-up study. It offered me a great opportunity to ponder physical activity behaviour, considering how it could be approached prospectively, in combination with massive health outcome and survey data. During this journey, there have been many people and organizations that I wish to acknowledge.

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I would like to express my special thanks to Professor Emeritus Lasse Kannas for teaching me so much in the early phases of my researcher's path. I deeply value your advice in conducting research. I'm grateful also to all my workmates (former and current) in the Faculty of Sport and Health Sciences. Conversations and laughter during these years have been important, and have promoted my health and wellbeing. There have always been wise colleagues to ask for help. I'm thankful also to our PhD student group and to my roommates for peer support and sharing.

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Tuula Aira

ORIGINAL PUBLICATIONS AND AUTHOR CONTRIBUTION

This thesis is based on the following original publications, which will be referred to by their Roman numerals. The thesis also includes unpublished data.

I Aira, T., Vasankari, T., Heinonen, O. J., Korpelainen, R., Kotkajuuri, J., Parkkari, J., Savonen, K., Uusitalo, A., Valtonen, M., Villberg, J., Vähä-Ypyä, H., & Kokko, S. P. (2021). Physical activity from adolescence to young adulthood: patterns of change, and their associations with activity domains and sedentary time. *International Journal of Behavioral Nutrition and Physical Activity*, *18*, Article 85. https://doi.org/10.1186/s12966-021-01130-x

II Aira, T., Vasankari, T., Heinonen, O. J., Korpelainen, R., Kotkajuuri, J., Parkkari, J., Savonen, K., Toivo, K., Uusitalo, A., Valtonen, M., Villberg, J., Vähä-Ypyä, H., & Kokko, S. P. (2023). Psychosocial and health behavioural characteristics of longitudinal physical activity patterns: a cohort study from adolescence to young adulthood. *BMC Public Health*, *23,* Article 2156. https://doi.org/10.1186/s12889-023-17122-4

III Aira, T., Kokko, S. P., Heinonen, O. J., Korpelainen R., Kotkajuuri, J., Parkkari, J., Savonen, K., Toivo, K., Uusitalo, A., Valtonen, M., Villberg, J., Niemelä, O., Vähä-Ypyä, H., & Vasankari, T. (2023). Longitudinal physical activity patterns and the development of cardiometabolic risk factors during adolescence. *Scandinavian Journal of Medicine & Science in Sports*, *33*(9), 1807−1820. https://doi.org/10.1111/sms.14415

As the first author of the original publications, considering the comments from the co-authors, I drafted the study questions, prepared the data for statistical analysis, and performed statistical analysis independently or with help from the statisticians. I also had the main responsibility for writing the manuscripts. The data for this dissertation come from the Diverging paths in physical activity and sports participation: Health Promoting Sports Club (HPSC) cohort study in which I worked as a project coordinator. Thus, I participated in planning the study protocol including the surveys. I also actively participated in the data collection by coordinating the recruitment of the participants.

FIGURES

TABLES

ABBREVIATIONS

BMI	Body mass index
CI	Confidence interval
HBSC	Health Behaviour in School-aged Children study
HDL	High-density lipoprotein
HOMA-IR	Homeostasis model assessment of insulin resistance
HPSC	Diverging paths in physical activity and sports participation: Health Promoting Sports Club (HPSC) cohort study
KmL	K-means algorithm for longitudinal data
LDL	Low density lipoprotein
MAD	Mean amplitude deviation
MET	Metabolic equivalent of task
MVPA	Moderate-to-vigorous physical activity
OR	Odds ratio
WHO	World Health Organization

CONTENTS

1 INTRODUCTION

The shift in Western societies towards a more sedentary lifestyle has raised concerns. These would appear to be justified bearing in mind that a sedentary lifestyle causes disease, and an economic burden related to human suffering (Ding et al., 2016). Insufficient physical activity is a risk factor for illness, including cardiometabolic diseases, which are among the most common causes of death year after year (Global Health Estimates, 2019). In recent years, the consequences of physical inactivity for planetary health (involving e.g. passive commuting), have also been a focus of attention (Jochem & Leitzman, 2023; UNESCO, 2015). Overall, the importance of physical activity for wellbeing is widely recognized at both global and national level (Finnish Government, 2023; UNESCO, 2015; World Health Organization, 2018).

Non-adherence to physical activity guidelines is common already from adolescence and even earlier (Guthold et al., 2020), coinciding with a general decline in activity with increasing age (Corder et al., 2019). Adolescence in particular is a life phase when dropout from sports clubs commonly occurs and activity decreases overall (Corder et al., 2019; Kemp et al., 2019).

While the overall decrease in physical activity during adolescence is well-established, the high degree of individual variation is often ignored. Many adolescents follow the general pattern of decreased activity, yet others increase or maintain high or low activity. Understanding these different patterns and the related correlates could be beneficial in tackling problems related to insufficient activity and supporting favourable behaviours.

In addition, the dynamic and time-varying nature of physical activity is insufficiently recognized in assessing health. The relation of physical activity at a single time point (adolescence) to later health outcomes (in young adulthood) is a common research approach (van Sluijs et al., 2021); however, it overlooks possible changes in physical activity behaviour (see also Moholdt et al., 2021; Sharma et al., 2023; Yang et al., 2022). Exploration of physical activity change and stability patterns in relation to the development of cardiometabolic risk factors makes it possible to observe (possibly varying) health outcomes over time – outcomes due to different forms of physical activity evolution. There are possibilities to determine, for example, whether a decrease in physical activity during adolescence has unfavourable health consequences already during this early life phase. Furthermore, in cases of maintained physical activity, it would be possible to determine whether this relates positively to cardiometabolic health as compared to maintenance of a passive lifestyle.

Overall, the life stage from adolescence to young adulthood has received only limited attention from the perspective of physical activity (Corder et al., 2009; Corder et al., 2019; Lounassalo, Salin et al., 2019; van Sluijs et al., 2021). This is surprising, given that this life period typically involves increasing autonomy, plus important changes such as moving out of the childhood family home, and entering higher education or employment. Thus, the transition to young adulthood can be seen as a particularly important time for the establishment of long-term lifestyle behaviours.

Physical activity measures have become more valid following the use of accelerometers. These devices have enabled more objective measures of movement as compared to participants' self-reports (Burchartz et al., 2020). Note also that in conducting a follow-up with accelerometers, with the aim of capturing patterns of change and stability, data-driven methods are preferable to subjective group identification. Data-driven methods make it possible to identify real patterns of change and stability. By contrast, traditional methods, by which data is subjectively forced into patterns based on pre-determined levels (such as quartiles), may well miss fine-grained developments in groups over time, as identified from the actual study data.

The research reported in this doctoral thesis aimed to identify patterns of physical activity change and stability among Finnish young people from adolescence to young adulthood (ages 15 to 19), and further to explore the characteristics (determinants or correlates) of the patterns in relation to 1) demographics, 2) the domains of physical activity, 3) sedentary time, 4) psychosocial factors, 5) health behaviours. A further aim was to study the associations between physical activity patterns and the development of cardiometabolic risk factors. The core phenomena of the study, i.e. longitudinal physical activity patterns, were thus studied in a multidisciplinary manner. The overall perspectives of health promotion and sports and exercise medicine were adopted, and these were used to extend the continuum from behavioural correlates to health outcomes.

2 REVIEW OF THE LITERATURE

2.1 The transition to young adulthood and health behaviour

The period from adolescence to young adulthood is one of the most fundamental transitions in life (Arnett, 2000; Hirvensalo & Lintunen, 2011). During this life stage, multiple changes occur, for example, biologically, demographically, and in terms of identity explorations (Arnett, 2000). The fundamental changes – such as transition to further studies or working life, moving away from the childhood family, or engaging in intimate relationships – influence subsequent life periods, and reflect independent decisions and growing responsibility for one's own life course (see also Arnett, 2000).

The transition to young adulthood is important also for health behaviours (defined here as intentional or unintentional actions taken by individuals that may affect health or mortality (modified from Short & Mollborn, 2015)) such as dietary habits, and physical activity. These behaviours have their foundations in childhood family practices, while increasing independence in adolescence enables decisions that are more in line with one's own preferences. However, in addition to personal attributes and family influences, health behaviours are influenced by one's broader social surroundings, the physical environment, and the overall policy framework, acting in a complex interplay (Bronfenbrenner, 1979; Sallis & Owen, 2015). These multilevel determinants of behaviour may vary across the life course, influencing each other and the way in which life unfolds (Mohammadi, 2019; Sharma et al., 2023; Tones & Tilford, 2011, pp. 195–199). This complexity in physical activity is discussed in more detail in Section 2.2.3, paying particular attention to the (socio)ecological model and the life course approach.

The terminology and age ranges describing young people vary (Figure 1). In this study, 15-year-olds are referred to as *adolescents* and 19-year-olds as *young adults*. The terms are based on the age of adulthood (18 years) as set by law (Laki holhoustoimesta 442/1999)[1], and for practical reasons, to separate the two age groups from each other. However, the common markers of adulthood – for instance becoming independent and responsible for oneself – develop with varying individual timings.

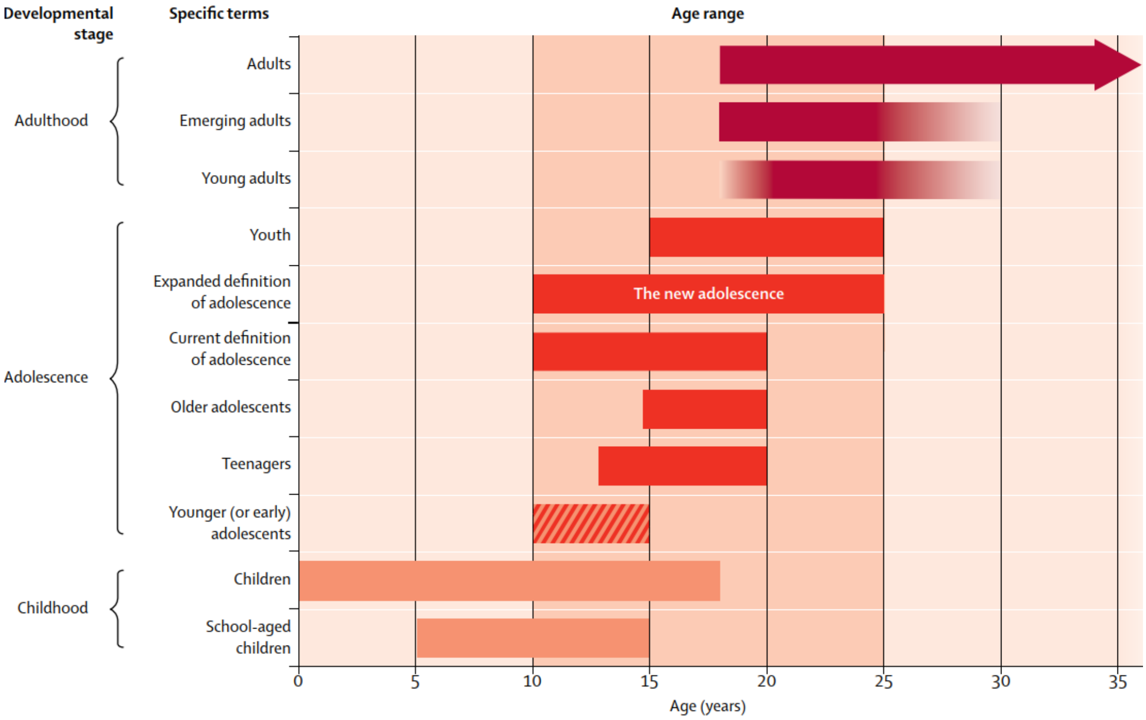

FIGURE 1 Commonly used age ranges and terms for childhood, adolescence and adulthood (Sawyer et al., 2018)

In Finland, a typical 15-year-old adolescent is a 9th grader in compulsory basic education or starting secondary education (either upper secondary school or vocational education and training). A 19-year-old young adult is in a transitional phase, in which the educational and occupational paths start to differ between individuals. Many 19-year-olds are still in upper secondary school or vocational school (in which education usually takes place between ages 15/16 and 18/19), but some have already proceeded to working life, higher education, or military service (which is obligatory for all Finnish men, and voluntary for women). Hence, many changes in everyday life settings and environments take place between adolescence and young adulthood potentially affecting health behaviours.

[1] Although by law individuals become adults at age 18, the Finnish Youth Act (Nuorisolaki 1285/2016) defines adolescents as persons under age 29.

2.2 Physical activity from adolescence to young adulthood

2.2.1 The concept of physical activity

Physical activity is widely recognized as a health-promoting behaviour. It was commonly defined (Caspersen et al., 1985) as any bodily movement produced by skeletal muscles that results in increased energy expenditure. Later, physical activity was defined more precisely as involving activities exceeding 1.5 metabolic equivalents (METs)[2]; this was in contrast with sedentary behaviour (any waking behaviour characterized by energy expenditure ≤ 1.5 METs, while in a sitting, lying or reclining posture), and sleep (~ 1 MET) (Tremblay et al., 2017). This approach takes into account movement and non-movement behaviours during a 24-hour period. Exercise is seen as one form of physical activity, as it is defined as planned, structured and repetitive form of physical activity, done for a specific purpose, e.g., to improve one's health or physical function (Caspersen et al., 1985).

Physical activity can further be described by its intensity, frequency, duration, type, and domain (see Table 1 with examples of these), as well as by the environments or settings where the activities take place. Hence, behavioural characteristics are relevant when describing physical activity. For example, the settings and environments in which people live their everyday lives mould and enable physical activity (see also Kokko & Baybutt, 2022; World Health Organization, 1986, p. 4). In Finland and many Western countries, typical settings for physical activities during adolescent and young adult years include 1) sports clubs and other organized sports, 2) educational settings from comprehensive school to vocational school and upper secondary school, and later higher education institution. Furthermore, the 3) occupational contexts and 4) the home and nearby community are common living environments in which daily physical activity may occur.

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2 '*The metabolic equivalent of task, or simply metabolic equivalent, is a physiological measure expressing the intensity of physical activities. One MET is the energy equivalent expended by an individual while seated at rest, usually expressed as mLO2/kg/min.*' (Bull et al., 2020)

TABLE 1 Examples of characteristics of physical activity with the guidelines on physical activity

<table>
<tr><th colspan="6">Characteristics of physical activity</th></tr>
<tr><td>Domains (Sallis et al., 2006, modified)</td><td>Active leisure</td><td>Active commuting</td><td colspan="2">Household activities</td><td>Occupational and/or educational activities</td></tr>
<tr><td>Types</td><td>Endurance (aerobic)</td><td>Resistance/ strength</td><td colspan="2">Balance</td><td>Flexibility</td></tr>
<tr><td rowspan="2">Aerobic intensity (Ainsworth et al., 2023; Bull et al., 2020)</td><td rowspan="2">Sleep ~1 metabolic equivalent (MET)</td><td rowspan="2">Sedentary behaviour ≤1.5 METs</td><td colspan="3">Physical activity >1.5 METs</td></tr>
<tr><td>Low, >1,5–2.9 METs (slow walking, light effort household tasks)</td><td>Moderate, 3–5.9 METs (brisk walk, vigorous effort household tasks)</td><td>Vigorous, ≥6 METs (running, playing basketball)</td></tr>
<tr><th colspan="6">Guidelines</th></tr>
<tr><td colspan="6">For children and adolescents (7–17 yrs)</td></tr>
<tr><td>Finnish recommendation (Ministry of Education and Culture, 2021)</td><td colspan="5">All children and adolescents aged 7 to 17 years are recommended to be physically active in a versatile, brisk and strenuous manner for at least 60 minutes a day in a way that suits the individual, considering their age. Excessive and extended sedentary activity should be avoided.</td></tr>
<tr><td>WHO's guideline (Bull et al., 2020)</td><td colspan="5">Children and adolescents should do at least an average of 60 minutes per day of moderate- to vigorous-intensity, mostly aerobic, physical activity, across the week. Vigorous-intensity aerobic activities, as well as those that strengthen muscle and bone, should be incorporated at least 3 days a week.</td></tr>
<tr><td colspan="6">For adults</td></tr>
<tr><td>Finnish recommendation for 18–65-year-olds (Vähä-Ypyä et al., 2022)</td><td colspan="5">Light physical activity as often as possible.
Moderate physical activity at least 2 h 30 min per week OR vigorous physical activity at least 1h 15 min per week.
Muscle strengthening and balance activities at least 2 times per week.</td></tr>
<tr><td>WHO's guideline for 18–64-year-olds (Bull et al., 2020)</td><td colspan="5">All adults should undertake regular physical activity;
► Adults should do at least 150–300 min of moderate-intensity aerobic physical activity, or at least 75–150 min of vigorous-intensity aerobic physical activity, or an equivalent combination of moderate-intensity and vigorous-intensity activity throughout the week for substantial health benefits.
► Adults should also do muscle-strengthening activities at moderate or greater intensity that involve all major muscle groups on 2 or more days a week, as these provide additional health benefits.
► Adults may increase moderate-intensity aerobic physical activity to >300 min, or do >150 min of vigorous-intensity aerobic physical activity, or an equivalent combination of moderate-intensity and vigorous-intensity activity throughout the week for additional health benefits (when not contraindicated for those with chronic conditions).</td></tr>
</table>

The aspect of physical activity as health-promoting behaviour is closely connected to the descriptions of physical activity, as the benefit of physical activity is dependent on its intensity, frequency, duration, and type, which are conveyed in physical activity guidelines (see Table 1). The physical activity guidelines are used as a reference also for the concept of physical inactivity. Note that according to the commonly accepted definition, physical inactivity is considered to be an activity level that is insufficient to meet the current physical activity guideline (Bull et al., 2020). However, when defining whether one is inactive, the only part of the guidelines commonly considered is unfulfilment of the aerobic physical activity recommendations (Guthold et al., 2018)[3].

It is notable that there is a remarkable difference between the guidelines for a 17-year-old adolescent and those for an (at least 18-year-old) young adult. To fulfil the recommendation of pursuing at least moderate intensity physical activity, an average of one hour per day, i.e. seven hours per week, is recommended for an adolescent, whereas two and a half hours per week is deemed sufficient for a young adult. This easily leads to a situation in which one is insufficiently active at adolescence, but on reaching the age of 18, the recommendation for adults is achieved (see e.g., Espinoza et al., 2023). There is no scientific reason for so sudden and significant a change in the recommended dose of physical activity at age 18 (van Sluijs et al., 2021). Hence, separate physical activity guidelines for young adults may be needed together with more research on the health benefits (see also van Sluijs et al., 2021).

2.2.2 Key physical activity settings and domains in Finland

Information on the settings and domains in which physical activity takes place is important in seeking to understand physical activity behaviour. The cultural context, including geographical distances, and also the laws on education, set some preconditions on people's use of time and their possibilities for physical activity. There also seems to be considerable variation between countries in how moderate-to-vigorous physical activity (MVPA) is accumulated via different physical activity domains (Strain et al., 2020).

In Finnish basic education, every pupil obtains school physical education comprising seven weekly lesson hours in total between the 7th and 9th school grades (ages 12/13 to 15/16) (Valtioneuvoston asetus, 2023). This is equivalent to 7 * 38 = 266 school lesson hours during grades 7, 8, and 9. One school lesson hour is timed as 45 minutes. The school can decide on the distribution of the weekly lesson hours per year, having, for example, two weekly lesson hours for 8th and 9th graders and three weekly lesson hours for 7th graders (Valtioneuvoston asetus, 2012, 2023). Additionally, schools may offer optional school physical education, varying in content and amount between schools. The average duration

[3] If one considers both aerobic and muscle-strengthening activities, adherence to the WHO's guidelines (Bull et al., 2020) is fulfilled by approximately one out of five adults (17%) (García-Hermoso et al., 2023). If one considers only aerobic physical activity, the corresponding prevalence is one in four adults (28%) (Guthold et al., 2018). However, the prevalence of adolescents fulfilling the aerobic physical activity guideline is the same as the corresponding prevalence based on both aerobic and muscle-strengthening activities (both 19%) (García-Hermoso et al., 2023; Guthold et al., 2020). The results are based on self-reports.

of school physical education in 2022 was 140 minutes per week according to 9th graders self-reports (Palomäki & Lyyra, 2023).

After basic education, just over half of adolescents continue to general upper secondary education, while around 40% of adolescents proceed to vocational education and training (Finnish National Agency for Education, 2019, pp. 15–16)[4]. The typical duration of secondary education is three years (from age 15/16 to age 18/19). During upper secondary education, there are two compulsory courses (2 * 38 hours) and three voluntary specialization courses (3 * 38 hours) of physical education (Finnish National Agency for Education, 2020). In vocational education and training, physical education is embedded in a 2 credits compulsory course related to the maintenance of worksite wellbeing (Finnish National Agency for Education, 2024). In some fields of vocational education and training, physical activity is an essential part of the studies (e.g. when one is aiming to become a physical-education instructor).

The Finnish Ministry of Education and Culture has funded a national action programme *Finnish School on the Move* to establish a physically active culture in schools since 2010 (Blom et al., 2018). The programme was first implemented in basic education (grades 1–9), and since 2015 it has been implemented also in upper secondary school and higher education (Blom et al., 2018). At present, more than 90% of schools in basic education participate in the programme (Liikkuva koulu, 2024).

Active commuting to and from the school or study place is part of the weekday of many young people. The distance between home and school is less than five kilometres for 62% of 7th and 9th graders (Turunen et al., 2023) and for 56% of upper secondary school students in Finland (Kallio et al., 2021). If the distance is more than five kilometres, the municipality arranges school transport for pupils in basic education (Basic Education Act 628/1998), but some parts of the trip may still be commuted actively. Out of those 7th graders who live less than five kilometres from school, 78% commute actively (by bicycle or on foot) to school (Turunen et al., 2023). The corresponding proportion among 9th graders is lower (59%), and it has been speculated that motorized vehicles such as mopeds might have replaced at least some part of cycling or walking to schools, since 15-year-olds have the possibility to get a driving licence for a moped (Turunen et al., 2023). However, 72% of upper secondary school students commute actively to their study place (Kallio et al., 2021).

After upper secondary education, young adults typically move on to higher education, working life, or military service. In higher education (universities and universities of applied sciences) sports services arrange physical activities for students. For its part, military service concerns all Finnish men deemed fit for service and women who wish to apply for it voluntarily. The service commonly starts within two years from call-ups arranged at the age of 18 (Finnish Defence Forces, 2023), and it includes training to improve the fitness of participants. The duration

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[4] Since 1.8.2021, compulsory education has been extended to the age of 18 (Oppivelvollisuuslaki 1214/2020), whereas previously only basic education was compulsory.

of military service is at least half a year (165 days), but can also be 255 or 347 days (Finnish Defence Forces, 2023).

Most organized leisure-time sports and exercise activities for adolescents in Finland are arranged by sports clubs. These are typically based on voluntary civic activities at local level, and only a minority of sports clubs operate as profit-making companies. Approximately two thirds of children and adolescents take part in sports club activities at present (Kokko et al., 2019), and there has been increasing participation over the years among persons aged 11 to 15 (Aira et al., 2013, p. 52; Räisänen et al., 2018). However, dropout from the sports club is common during adolescence (Aira et al., 2013). In Finland, 42% of 15-year-olds take part in sports club activities (Blomqvist et al., 2023), whereas the corresponding prevalence is 30% among upper secondary school students aged 18–20 (Mononen et al., 2021).

In addition to sports clubs, young people take part in organized leisure-time sports via (i) sports companies (27% of 9^{th} graders and 30% of upper secondary school students on a weekly basis), (ii) school clubs (14% of 9^{th} graders and 6% of upper secondary school students), or (iii) clubs set by other organizations such as Scouts (13% of 9^{th} graders and 9% of upper secondary school students) (Kokko et al., 2021; Martin et al., 2023). Recently, new provisions were added to the Youth Act (Laki nuorisolain muuttamisesta 955/2022) concerning recreational activities for young people and the state subsidy grant for such activities in basic education. In practice, school clubs – some consisting of physical activities – are offered to pupils free of charge.

There has also been research on how much MVPA is accumulated via distinct physical activity domains, as measured by an accelerometer or corresponding device. International studies have shown that most school physical education lessons (approximately two thirds) for persons aged 12–18 are spent on, at most, low intensity physical activities (Hollis et al., 2017). The time spent in MVPA during sports club practices has been estimated at 40–50% (Ridley et al., 2018). However, the recommended amount of MVPA may be achieved through a range of physical activity domains. For example, almost half of the recommended amount of MVPA for adolescents may be achieved through active commuting (Campos-Garzón et al., 2023).

Few studies have analysed changes in physical activity domains in association with changes in MVPA during adolescence or young adulthood (Ikeda et al., 2022). Moreover, individual variation is not taken into account if one analyses only the average participation in different domains of physical activity.

2.2.3 Correlates and determinants of physical activity

Understanding why people are active or inactive is a key question in physical activity promotion. Several studies have examined how different factors determine physical activity behaviour. According to a recent review, the main determinants and correlates for physical activity in adolescence include male gender, social support from friends and family, an activity-supportive built environment, and support for activity in the whole school and in physical education classes in particular (van Sluijs et al., 2021).

In physical activity research, a determinant of physical activity is understood as a predictor possessing a possible causal relationship with physical activity (Atkin et al., 2016; Bauman et al., 2002, 2012) or (more briefly) as a preceding predictor (Hesketh et al., 2016). Thus, it is differentiated from a correlate of physical activity, which refers to a cross-sectional association without the possibility to examine causality (Atkin et al., 2016; Bauman et al., 2002, 2012; Sallis et al., 1992). In health promotion terminology, for its part, a determinant is a factor which determines the healthy life expectancy of individuals and populations (Nutbeam & Muscat, 2021) or – as adjusted to the framework of this study – one that determines physical activity. The definition gives no indication of possible causality.

The notion of a determinant is complex, insofar as it is difficult to reveal causal pathways reliably in the absence of randomized controlled studies. These, however, also have limitations when one is exploring human behaviour outside the laboratory, as multiple factors may contribute to an outcome in real life. In addition, causal relationships may be bidirectional (a phenomenon called reciprocal determinism) (Bauman et al., 2002). For example, overweight may cause lower activity and vice versa. Overall, it frequently happens that causal determination cannot be confirmed (Biddle et al., 2023). Despite the limitations with regard to proving causality and the lack of a consensus in the terminology, the current study on physical activity will apply the above-mentioned definitions of *determinant* and *correlate* as they are commonly used when physical activity is under examination. In those cases where the analyses have been conducted in a longitudinal setting, but a factor (an exposure variable) cannot be said to precede an outcome (for example, in the case of longitudinal physical activity patterns as outcome), the term *longitudinal correlate* is also used.

2.2.3.1 The ecological framework

The diversity of correlates and determinants of physical activity is illustrated in (socio)ecological models. The ecological framework is based on the idea that human behaviour is influenced by both individual characteristics and physical and sociocultural environments (Sallis & Owen, 2015). Thus, as the name suggests, the ecological framework acknowledges also the environmental influences on human behaviour.

The ecological framework further aims to categorize diverse behavioural influences (see, for example, Sallis & Owen, 2015). Bronfenbrenner (1979, pp. 7–8) was one of the first researchers to differentiate between distinct levels of behavioural influences, as being closer to the individual (in a microsystem) or more distant from the individual (in meso- and exosystems). McLeroy et al. (1988), for their part, distinguished between intrapersonal, interpersonal, institutional, community, and policy levels. All these categorizations can be useful in seeking to understand the plurality of possible determinants and correlates in human behaviour.

The ecological framework has been widely applied to physical activity research (Sallis & Owen, 2015). Sallis et al. (2006) illustrated an ecological model involving four domains of active living; hence, 1) active recreation, 2) household activities, 3) active transport, and 4) occupational activities were acknowledged as having their own specific context or setting, characteristics, and possible policies, each of which could play a role in the individual's physical activity behaviour. Bauman et al. (2012) categorized the determinants of physical activity within the following levels over the life course: *individual*, *interpersonal*, *environment*, *regional or national policy*, and *global* (see Figure 2). The combinations and interactions of factors from these levels can be expected to influence physical activity (Bauman et al., 2012).

The ecological framework can be used also in combination with other behavioural theories or models. The ecological models do not necessarily specify the factors or processes at each level that might influence behaviour, and other models might thus be beneficial (Sallis & Owen, 2015). For example, at an individual level, the Health Belief Model (Hochbaum, 1958) concentrates on the personal *expectancy* and *value* of a given behaviour, whereas Social Cognitive Theory (Bandura, 1986) considers also the interpersonal level, focusing, for example, on *social support*, *normative beliefs,* and *observational learning*. Furthermore, there are other frameworks, such as the Behaviour Change Wheel (Michie et al., 2011), that take the ecological framework to the level of behavioural change (van Kasteren et al., 2020).

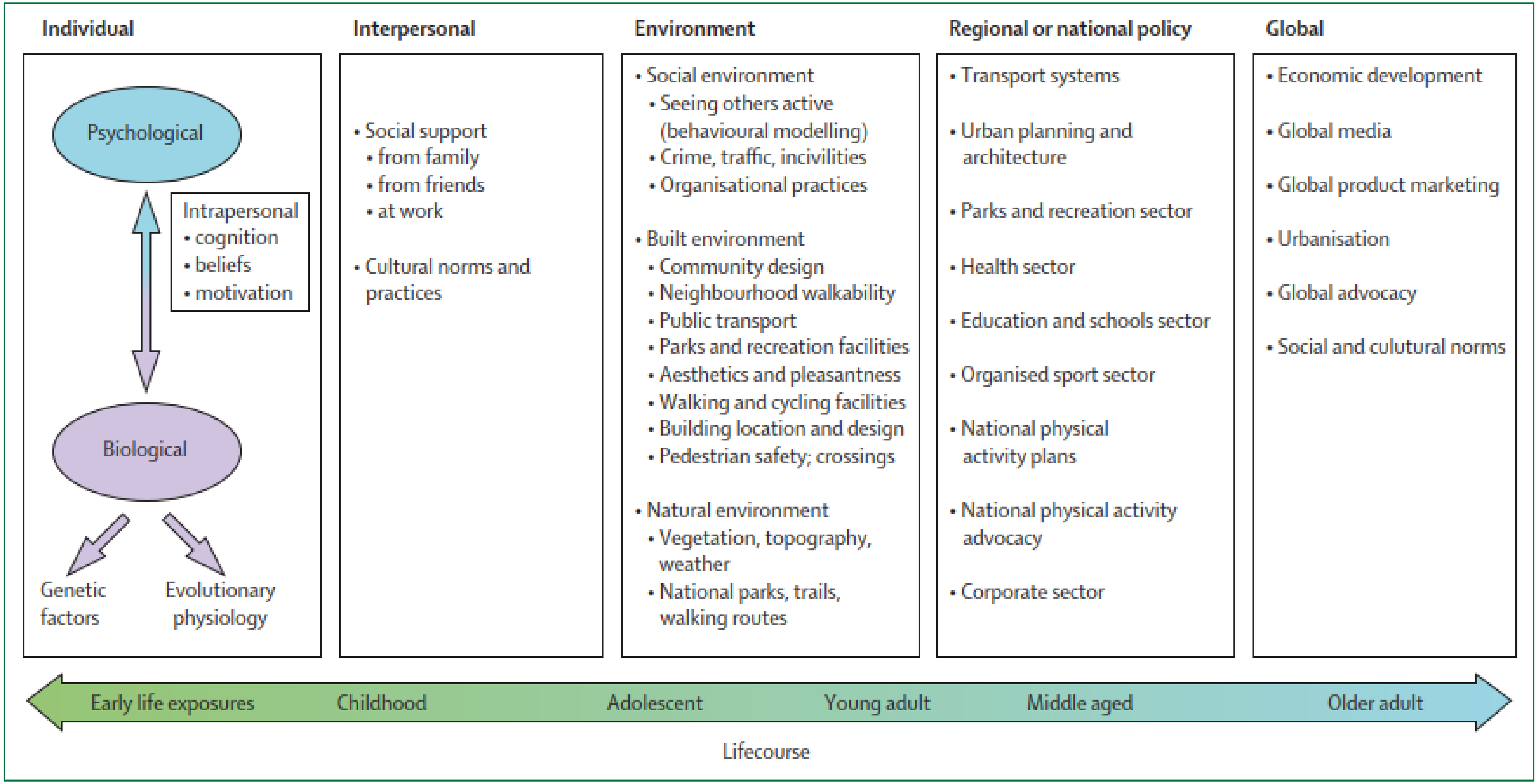


FIGURE 2 Adapted ecological model of the determinants of physical activity (Bauman et al., 2012)

2.2.3.2 The life course approach

The life course approach emphasizes the events and transitions occurring during different life phases, and the consequences of these for behaviour and health (Halfton et al., 2014; Tones & Tilford, 2011, pp. 195–199). Thus, health development is seen as a dynamic and adaptive process continuing throughout the lifespan (Halfton et al., 2014). This process starts before birth and conception, since the environment affects the formation of the organism and the developing foetus via e.g. the neural-hormonal context and nutritional inputs (Halfton et al., 2014).

In addition to genetics and biological factors, health and behaviour throughout the life course is influenced by social and psychological aspects (Halfton et al., 2014), as well as by the physical environment and policy. Hence, the life course approach to some degree includes the ecological framework, intertwining individuals and contexts with a cross-cutting emphasis on time (Li et al., 2009). Bauman et al. (2012), too, have adapted the notion of the 'life course' (from early life exposure to older adulthood) within the ecological model of the determinants of physical activity (see Figure 2), although this aspect is only mentioned briefly.

Mielke (2022) has pointed out that assumptions regarding the causes and consequences of behaviour may be overly simplistic if the time-varying nature of behaviour and its determinants is not considered. Furthermore, by observing behaviour as a trajectory, it may be possible to identify the key life stages in which changes occur and examine the associated determinants (Ben-Shlomo et al., 2016; Sharma et al., 2023).

Li et al. (2009) have summarized the following key elements of the life course approach from the writings of Elder et al. (2003): 1) human agency, 2) linked lives, 3) time and place, 4) life-span development, and 5) timing. *Human agency* indicates individuals who actively make decisions for their own lives. *Linked lives* refers to individuals who are not isolated from others but rather bound to the lives of others. Historical time and geography (*time and place*) also play a role in how the life course proceeds. Furthermore, earlier life phases may impact on one's forthcoming life (*life-span development*). Finally, *timing* is important, as there may be ideal times for intervening e.g. in health behaviours (Elder, 1998).

When considering physical activity behaviour during the transition to young adulthood, the contexts of living and of physical activity are special targets of interest, because they are usually changing (see also Hirvensalo & Lintunen, 2011). These changes may cause adaptation to physical activity, and possibly determine physical activity change. According to some studies, starting employment (Gropper et al., 2020; Winpenny et al., 2020), starting cohabitation, getting married, pregnancy, and the transition from high school to college are associated with a decrease in physical activity (Gropper et al., 2020). By contrast, leaving the university does not appear to be related to changes in physical activity (Winpenny et al., 2020). However, the conclusions regarding the relations between life events and changes in physical activity are based on a limited number of heterogeneous studies. In addition to life events, it is necessary to examine also other possible determinants and correlates playing a role in physical activity change and stability in adolescence and young adulthood.

2.2.3.3 Other contextual considerations

In the previous sections above, physical activity was discussed in terms of the diversity in multilevel correlates and determinants within an ecological framework and over the life course. The contextual factors can also be considered beyond the ecological framework or life course approach.

Atkin et al. (2016) have summarized the context as consisting of activity *type*, *person*, *place*, and *time* – all causing variation in physical activity behaviour and its correlates. Indeed, different *activity types* such as walking and jogging, but also different activity domains (active commuting and sports club participation) and intensities (low and vigorous physical activity) (Biddle et al., 2023) may have their own correlates and determinants. Furthermore, Dishman et al. (1985) noted already during the 1980s that influences on participation in physical activity may vary for different activity behaviours.

In addition to the variation deriving from different life phases, shorter periods of time may be relevant. For instance, there may be considerable variation in determinants between weekend and weekday activities (Corder et al., 2013). Moreover, specific groups of people – such as disabled people, or persons with some chronic disorder – may have unique determinants for physical activity (see also Sallis et al., 1992). The stage of behaviour change from pre-contemplation to maintenance is also a possible source for variation in physical activity correlates (Biddle et al., 2023). The common demand for more studies conducted in low-income countries rather than high-income countries (van Sluijs et al., 2021) is an example of *place* as a possible reason for differences in correlates for physical activity.

When considering a longitudinal perspective, the determinants of *change* in physical activity (Craggs et al., 2011; Hesketh et al., 2017) may be different from the corresponding determinants of physical activity *at a certain time point*. Apart from research on overall determinants of change, studies have been conducted on determinants of change in school travel mode (Irwin et al., 2021) and in organized sports participation (Rinta-Antila et al., 2023).

The *changes in correlates* – how correlates might change over time and how these changes might relate to changes in physical activity – have so far received only limited attention. This research gap has also been noticed by others (Biddle et al., 2023).

2.2.4 Characterizing physical activity change and stability: longitudinal physical activity patterns

Longitudinal studies have demonstrated an average decline in physical activity from adolescence to young adulthood (Corder et al., 2019; Kwan et al., 2021). Moreover, the stability of physical activity during this life period is low to moderate (Hayes et al., 2019), meaning that the maintenance of one's physical activity over time relative to peers is moderate at most. This research methodology involves what is referred to as a tracking approach. Neither of these approaches (taking a population average of physical activity development or using a tracking approach) fully considers the variation in how physical activity develops over time across individuals. While a decline in physical activity is indeed common, other patterns of change and stability also exist. For example, Kwon et al. (2015b) identified four trajectories between ages 5 and 19: consistently inactive (15%), consistently active (18%), decreasing moderate physical activity (53%), and substantially decreasing high physical activity (14%). In some studies, a subgroup of activity increasers has been further identified, with a prevalence varying between 7% and 14% (Rangul et al., 2011; Young et al., 2018; Zook et al., 2014).

The establishment of physical activity patterns exemplifies person-centred research. From a methodological point of view, a person-centred approach means clustering people as opposed to variables (Woo et al., 2018). Instead of a single developmental pattern over time, the aim is to reveal distinct patterns, such that the within-pattern differences are as small as possible. There are multiple different data-driven methods to formulate the patterns, classifiable as (i) model-based methods (such as mixture modelling techniques or latent class analysis) and (ii) non-parametric algorithms (such as hierarchical or partitional clustering, applying e.g. K-means for longitudinal data) (Genolini & Falissard, 2010). In some studies, the identification of the distinct patterns is based on subjectively determined limits, for example, the fulfilment of physical activity guidelines. However, it can be claimed that only data-driven methods allow one to identify groups that are genuinely distinct from each other.

The identification of different longitudinal physical activity patterns has become more common in recent years, but there is no consistency in the terminology used. In addition to patterns, physical activity (its change and stability) has been presented via *trajectories* especially in studies using trajectory modelling (Beltran-Valls et al., 2019; Kwon, et al., 2015a; Pate et al., 2019; Rovio et al., 2018), but also in studies using other methods (Demmelmaier et al., 2016; Zook et al., 2014). Moreover, *profiles* (Rovio et al., 2018), *groups* (Young et al., 2018), *subgroups* (Farooq et al., 2018), and *clusters* (Young, et al., 2018) have been used when referring to population distributions on the basis of physical activity change or maintenance over time. This doctoral thesis refers to *longitudinal physical activity patterns* or (in brief) *physical activity patterns*, because the development of physical activity was observed via two measurement points. By contrast, the term trajectory usually refers to physical activity development examined over more than two time points. Note also that the thesis uses the terms *(sub)groups* and *clusters* as synonyms for patterns in explaining, for example, the formulation of physical activity patterns. Moreover, it refers to *patterns of change and stability,* as required to accurately describe the relevant phenomena.

Physical activity change overall may have different correlates and determinants from those applicable to longitudinal physical activity patterns. While the former focuses on background factors for the activity change in the entire study population, the latter assumes that there could be different factors associated with e.g. increasing, decreasing, and maintaining activity patterns. Table 2 summarizes the few studies whose focus has been on the determinants or correlates of longitudinal physical activity patterns during the transition to young adulthood. Only studies that used an accelerometer to measure MVPA are included. All the studies are from the USA, and they have differing target groups. In the study by Zook et al. (2014), the participants were females aged 14 at baseline, whereas the studies by Kwon et al. (2015b, 2016) set the baseline at age 5, and included both females and males. In the study by Zook et al. (2014), the follow-up did not quite reach the adult age, and pattern detection was based on subjective groupings via pre-determined levels.

Besides the studies shown in Table 2, other researchers have had similar study interests, but have based their findings on self-reported (leisure-time) physical activity (Kwon, Lee, & Carnethon, 2015) and on the subjective determination of longitudinal physical activity patterns (Aarnio et al., 2002; Rangul et al., 2011). In addition to analysing self-reported leisure-time physical activity, some studies have extended the follow-up to late young adulthood (e.g. Lounassalo et al., 2021; Mathisen et al., 2023; Rovio et al., 2018) making it difficult to draw conclusions on the transition to young adulthood.

The previously studied possible correlates and determinants for young people's physical activity patterns have been related to factors classifiable as follows: 1) *individual* (involving e.g. the physical self-concept (Zook et al., 2014) and, BMI (Rangul et al., 2011; Zook et al., 2014), 2) *interindividual* (involving social support (Kwon et al., 2016; Zook et al., 2014), and 3) *environmental* (distance to nearest park (Zook et al., 2014). Overall, the research base is limited, and apart from family and peer support for physical activity, the psychosocial factors associated with physical activity patterns have received little attention. Moreover, for the most part, only a single health behaviour has been studied in relation to longitudinal physical activity patterns. The behaviours have included sleep duration (Zook et al., 2014) and smoking/alcohol consumption (Rangul et al., 2011), but there would be reason to examine the possible accumulation of behavioural risk and/or protective factors. Similarly, many domains of physical activity have not been explored comprehensively and simultaneously, although the associations between organized sports participation and physical activity patterns have been examined (Kwon et al., 2015b; Rangul et al., 2011).

TABLE 2 Studies reporting correlates or determinants (covariates) for physical activity patterns from adolescence to young adulthood, in which the identification of patterns was based on moderate-to-vigorous physical activity assessed by an accelerometer

Ref.	Measurement ages; baseline year(s); country	N	Accelerometer; pattern identification	Method (possible reference)	Studied correlates / determinants	Main findings
Zook et al., 2014	Only females: 14, 17 (8th and 11th grades); 2005-2006; Washington, DC/Baltimore area, USA	561	ActiGraph; subjective, limit for grouping 30 min MVPA/day	Multivariable logistic regression (ref. all the other participants?)	Incl.: race; employment status; BMI; age at menses; sleep duration; previous organized PA; PA self-efficacy; perceived body fat; friend and family support for PA; frequency of PA with friends score; distance to nearest park; distance to school	*Adopters*: higher physical self-concept; lower odds for overweight *Active maintainers*: higher physical self-concept; higher social support for PA from friends and family; shorter distance to nearest park *Inactive maintainers*: higher odds for overweight; earlier menses; lower self-concept and lower perceived body fat; lower friend support for PA; less PA with friends; greater distance to school *Relapsers*: no predictors
Kwon et al., 2015b	5, 8, 11, 13, 15, 17, 19; 1998–2000; Iowa, USA	537	ActiGraph; group-based trajectory analysis (STATA TRAJ procedure) for MVPA	Dual trajectory analysis	Television viewing trajectory groups; organized sports participation trajectory groups	None of the *consistently actives* were categorized in the *no sports participation* group. The healthiest TV viewing pattern (*decreasing low TV viewing*) was associated with the *consistently active* pattern.
Kwon et al., 2016	5, 8, 11, 13, 15, 17, 19; 1998–2002; Iowa, USA	365	See: Kwon et al., 2015b	Multinomial logistic regression (ref. *consistently active*)	Sex; family SES and PA engagement in high school and adulthood by father and/or mother; family support for PA and sports	Lower family support; female sex; lower family SES & no regular PA in high school by parents; low family SES & regular PA in high school by father associated with *decreasing from moderate MVPA*; Higher family support; lower family SES & no regular PA in high school by parents; lower family SES & regular PA in high school by father associated with *substantially decreasing from high MVPA.*

BMI = body mass index; MVPA = moderate-to-vigorous physical activity; PA = physical activity; SES = socioeconomic status

2.3 Cardiometabolic health among adolescents and young adults

Type 2 diabetes and cardiovascular diseases (including ischaemic heart disease and stroke) are among the leading causes of death worldwide (Global Health Estimates, 2019; Mensah et al., 2023; Roth et al., 2020). Although cardiometabolic diseases (type 2 diabetes and cardiovascular diseases) typically emerge in late adulthood, disease development may start as early as childhood and adolescence (Berenson et al., 2005; Jacobs et al., 2022; McGill et al., 2000; Pool et al., 2021; Raitakari et al., 2023). Thus, health promotion initiatives should also be aimed at children, young people, and their families, bearing in mind that health habits start to form at an early age (National Heart, Lung, and Blood Institute, 2012).

Pathologically, the atherosclerotic vascular process begins with the accumulation of abnormal lipid in the carotid intima, progressing later to a stage in which the core of extracellular lipid is covered by a fibromuscular cap, and finally to thrombosis, vascular rupture, or acute ischaemic syndromes (National Heart, Lung, and Blood Institute, 2012, p. 8).

The most common cardiovascular risk factors include (i) measurable risk factors (high blood pressure, abnormal lipid levels, overweight/obesity, diabetes, low physical fitness), (ii) behavioural factors (tobacco exposure, physical inactivity, and poor nutrition/diet), (iii) conditions of life (family history, age, gender), and (iv) emerging risk factors (metabolic syndrome, inflammatory markers, perinatal factors) (Kodama et al., 2009; National Heart, Lung, and Blood Institute, 2012, p. 7). Ideal cardiovascular health consists of seven healthy behaviours and factors, namely non-smoking, sufficient physical activity, a healthy diet, BMI in the normal range, as well as normal blood pressure, glucose, and lipoprotein levels (Maclagan & Tu, 2015).

Type 2 diabetes is a metabolic disorder in which the plasma glucose concentration is chronically elevated due to decreased insulin action and insulin secretion, leading to a higher risk for acute and long-term complications (Alberti & Zimmet, 1998). Type 2 diabetes has similar risk factors to those for cardiovascular disease. These include (i) demographic (age, sex, race and ethnicity), (ii) genetic and epigenetic, and (iii) behavioural and lifestyle-related risk factors (unhealthy nutrition; physical inactivity; obesity; early life environmental factors such as low birth-weight; low socioeconomic status; sleep disturbances; depression and antidepression medication use; smoking) (Ley et al., 2018). Metabolic syndrome is especially powerful risk factor for development of type 2 diabetes (Ley et al., 2018). It involves risk factor clustering (central obesity, plus any two of the following factors: raised fasting glucose, raised blood pressure, raised triglyceride, reduced high-density lipoprotein cholesterol (HDL) levels) (Alberti et al., 2006).

For the measurable cardiometabolic risk factors, cut-offs have been set, which indicate possible increased cardiometabolic risk. Table 3 summarizes common thresholds for adolescents and young adults. Note, however, that the cutoffs for children and adolescents are problematic, because (for instance) lipid levels, blood pressure and BMI change with age and pubertal development (Zimmet et al., 2007). Moreover, there is variation in the cut-offs between different sources (Alberti et al., 2006; Cornier et al., 2008; Reisinger et al., 2021); also to take an example no consensus exists on the cut-off for the homeostasis model assessment of insulin resistance (HOMA-IR), which is influenced by sex, age, and race (Tahapary et al., 2022). According to a review (Arellano-Ruiz et al., 2019), the detected HOMA-IR cut-off for children and adolescents has varied between 2.3 and 3.59. More recently, higher cut-off values have been introduced (e.g. 5.0 for persons aged 11 to 15) (Hammel et al., 2023).

TABLE 3 Commonly used levels indicating a higher risk for cardiometabolic diseases, age 15 upwards

Glucose	**≥5.6 mmol/L** (Alberti et al., 2006; Zimmet et al., 2007)
Insulin	Age 15 (11 to 15): **≥20.8 mU/L** Age 19 (16 to 23): **≥16.5 mU/L** (Hammel et al., 2023)
Cholesterol	**≥5.0 mmol/L** (Piepoli et al., 2016)
Low density lipoprotein (LDL) cholesterol	**≥3.0 mmol/L** (Piepoli et al., 2016)
High density lipoprotein (HDL) cholesterol	Age 15 (10 to 16): **≤1.03 mmol/L** (Zimmet et al., 2007) Adults: males **<1.00 mmol/L**; females **≤1.20 mmol/L** (Piepoli et al., 2016)
Triglycerides	**≥1.7 mmol/L** (Piepoli et al., 2016; Zimmet et al., 2007)
Body mass index	Age 15: males **>23.3 kg/m²** females **>23.9 kg/m²** (Cole et al., 2000, 2007) Age 18 and older: **≥25 kg/m²** (World Health Organization, 2000)
Blood pressure (systolic/diastolic)	**>130/85 mm Hg** (Alberti et al., 2006; Zimmet et al., 2007)[5]

2.3.1 Cardiometabolic health benefits of physical activity

Research conducted among the adult population shows that physical activity is associated with a lower mortality rate (Katzmarzyk et al., 2022; Yang et al., 2022), and a lower incidence of cardiovascular diseases (Ramakrishnan et al., 2021) and type 2 diabetes (Kyu et al., 2016). The mechanism leading to the reduction of risk from these diseases and to lesser mortality may involve physical activity, which could cause a favourable development in the risk factors.

[5] Or ≥120/80 mm Hg (Flynn et al., 2017; Whelton et al., 2018)

The evidence from randomized controlled trials shows, that physical activity (exercise training) improves lipid profiles and glucose metabolism. More precisely, lower levels of triglycerides and higher levels of HDL cholesterol and apolipoprotein A1, as well as lower levels of fasting insulin and HOMA-IR, have been found in exercise groups as compared to controls (Lin et al., 2015). According to the review by Lin et al. (2015), physical activity also lowered total cholesterol and LDL cholesterol among participants who had some pre-existing medical condition such as type 2 diabetes, hypertension, or metabolic syndrome. Furthermore, physical activity lowers blood pressure (both systolic and diastolic) (Cornelissen & Smart, 2013) and reduces body adiposity (Armstrong et al., 2022).

The benefits of physical activity for children and adolescents have also been studied. Pool et al. (2021) had mixed findings regarding less physical activity in childhood being associated with adulthood cardiovascular disease. However, the studies were mostly based on self-reported physical activity, and the cardiovascular events were studied in persons around 30−40 years of age, a phase when cardiovascular diseases are rare (Pool et al., 2021).

The WHO's physical activity guidelines for children and adolescents (Bull et al., 2020) are based on a summary of research evidence indicating that a higher amount of physical activity is associated with improved health (including cardiometabolic health, but also bone health, and the risk of depressive symptoms) (Chaput et al., 2020). The reviews of randomized controlled studies examining the effectiveness of physical activity interventions were summarized, indicating consistent evidence that interventions were associated with better cardiometabolic outcomes (World Health Organization, 2020). However, the results varied as regards which health outcomes improved, and also which kinds of physical activities were examined, e.g. high-intensity interval-training and school-based programs (World Health Organization, 2020). Only a few studies found positive effects of resistance training on measures of cardiometabolic health (Bea et al., 2017).

Similarly, physical activity in adolescence (here defined as 10–24 years) might be associated with certain cardiometabolic health benefits (in terms of blood pressure, diabetes incidence, and metabolic syndrome) later in life, but the strength of the evidence so far has been low (van Sluijs et al., 2021). In the review by van Sluijs et al. (2021) the association of physical activity behaviour in adolescence with later health outcomes was studied, but the development of physical activity over time was not considered. As van Sluijs et al. (2021) noted, more research is needed, particularly in respect of older adolescents (young adults). There is a particular need for studies that would take into account changes in physical activity in relation to cardiometabolic outcomes, whether by randomized controlled trials or by observational studies. One example of an observational study is that conducted by Waterworth et al. (2024), who found that baseline self-reported physical activity and the change in physical activity were associated with a smaller increase in diastolic blood pressure over the 4-year measurement period (between ages 11 and 16).

2.3.2 Longitudinal physical activity patterns and the development of cardiometabolic risk factors

Very few studies have examined the association of longitudinal physical activity patterns with cardiometabolic risk factors during the transition from adolescence to young adulthood. It has been more common overall for longitudinal studies to examine either (i) *baseline physical activity* in relation to a follow-up cardiometabolic outcome, or change in the outcome, or (ii) the association between *a change in physical activity* and a change in the cardiometabolic outcome (García-Hermoso et al., 2021; Skrede et al., 2019; Tarp et al., 2016). However, neither of these approaches takes into account of the fact that distinct patterns of physical activity evolution might result in different cardiometabolic outcomes, depending on the *baseline physical activity level*, and also on the *magnitude of the change in physical activity*. Thus, there is a need to analyse differences in cardiometabolic risk factors between subgroups of adolescents with different physical activity changes over time (see also Bauman et al., 2017; Moholdt et al., 2021).

Table 4 summarizes the studies in which physical activity was measured by accelerometer and by longitudinal physical activity patterns identified via a data-driven method. Based on the two studies conducted (Kwon et al., 2015a; Oh et al., 2021), decreased activity during adolescence seems to be associated with higher odds of becoming obese and having a higher accumulation of body fat as compared to participants who maintain a high level of MVPA.

No corresponding studies have explored the association between physical activity patterns and blood biomarkers. Nevertheless, blood biomarkers have been analysed in some studies using self-reported leisure-time physical activity, with classification of physical activity patterns according to pre-determined levels (Raitakari et al., 1994; Rangul et al., 2012). In one study, activity maintainers had better HDL cholesterol levels in young adulthood (adjusted for age and gender) than inactive maintainers (Rangul et al., 2012). In another study, young women and men maintaining high physical activity had lower serum triglyceride values, and among men, also a lower concentration of insulin and a higher HDL cholesterol/total cholesterol ratio in young adulthood, as compared to study participants who maintained an inactive lifestyle (Raitakari et al., 1994). However, the latter results involved rough comparisons without adjustments, for example, without adjustment for age in the analysis. In addition to blood biomarkers, studies have indicated that lower diastolic blood pressure, body adiposity (BMI and waist circumference) (Rangul et al., 2012), and subscapular skinfolds (Raitakari et al., 1994) are related to sustaining high leisure-time physical activity from adolescence to young adulthood.

TABLE 4 Studies reporting associations of physical activity patterns with cardiometabolic health outcomes, in which physical activity was measured via an accelerometer and patterns identified by a data-driven method

Ref.	Measurement ages; baseline year(s); country	N	Accelerometer; pattern identification	Method	Studied cardiometabolic health outcomes	Main findings
Kwon et al., 2015a	5, 8, 11, 13, 15, 17, 19; 1998–2000 Iowa, USA	433	ActiGraph; Group-based trajectory analysis (STATA TRAJ procedure) for moderate-to-vigorous physical activity (MVPA)	Multivariable logistic regression model	Becoming obese (based on dual-energy X-ray absorptiometry (DXA) measurement of percentages of body mass)	As compared to consistently active participants (maintaining approximately 45 min. of daily MVPA), participants with decreasing activity had higher odds for becoming obese. Models were adjusted by sex, mother's education, somatic maturation, and energy intake.
Oh et al., 2021	15, 17, 19, 21, 23; 2007; Midwest, USA	297	ActiGraph; Latent trajectory analysis (SAS TRAJ procedure) for MVPA	Multivariable linear regression	Fat mass index (FMI); visceral adipose tissue mass index (VAT)	Consistently active participants (maintaining high MVPA) had a lower FMI z-score at age 23, independent of FMI at age 15 years, as compared to participants who decreased their activity from a moderate level. There was no significant association between the MVPA trajectory group and the VAT mass index.

3 AIMS OF THE STUDY

The purpose of this doctoral thesis was to identify patterns of physical activity change and stability from adolescence to young adulthood (ages 15 to 19) among Finnish young people, and to explore the characteristics (determinants or correlates) of patterns in relation to 1) demographics, 2) domains of physical activity, 3) sedentary time, 4) psychosocial factors, 5) health behaviours. In addition, the aim was to study the associations between physical activity patterns and cardiometabolic risk factors. Figure 3 illustrates the components of the thesis. The specific research questions for the sub-studies were:

I What kinds of longitudinal physical activity patterns can be identified among young people in Finland from adolescence to young adulthood (ages 15 to 19) and what are the demographic characteristics of the subgroups (including residence circumstances and education/occupation status) representing these patterns?

How are changes in different domains of physical activity (sports club participation, active commuting) and in sedentary time associated with physical activity patterns?

II How are health behaviours (smoking, alcohol intake, snuff use, amount of sleeping, dietary habits) and psychosocial variables (e.g. loneliness, difficulties in talking to parents) related to physical activity patterns?

III How are physical activity patterns associated with evolution in cardiometabolic risk factors (blood lipids, glucose metabolism, blood pressure, and BMI) from adolescence (age 15) to young adulthood (age 19)?

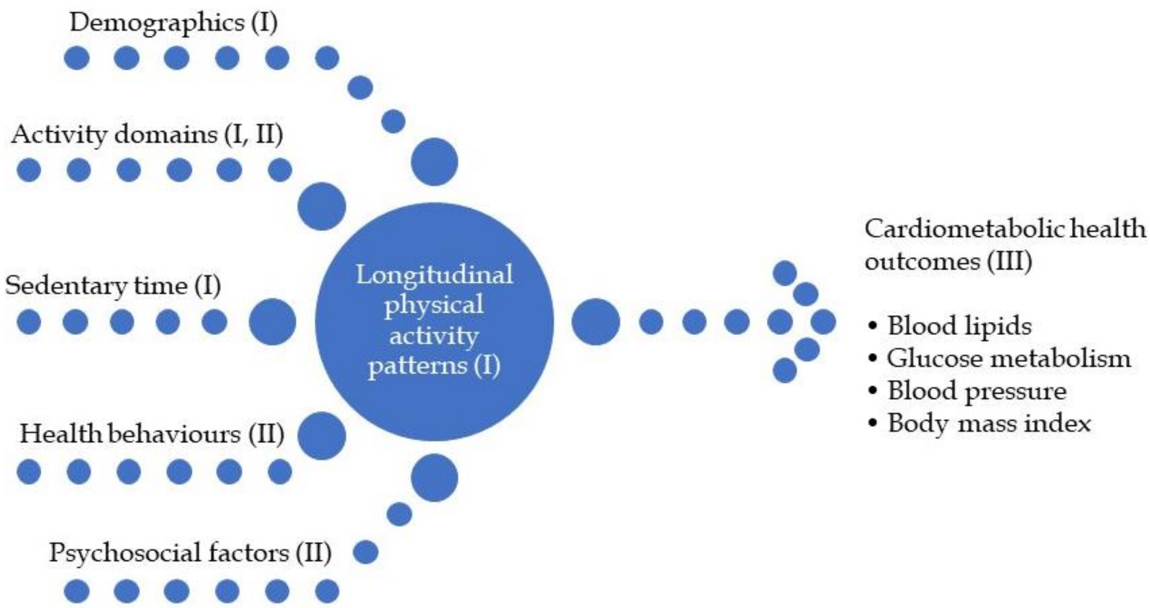


FIGURE 3 The components of the thesis: characteristics of the physical activity patterns, and relationship with cardiometabolic health

4 MATERIALS AND METHODS

4.1 Study design and participants

The study data form part of the *Diverging paths in physical activity and sports participation: Health Promoting Sports Club (HPSC) cohort study*, whose purpose was originally to examine cross-sectionally the differences in health behaviours and health status between sports club participants and non-participants, plus the health promotion activities of sports clubs (Kokko et al., 2015). Later, the study continued as a prospective follow-up study involving the same adolescents whose mean age was 15 years at baseline (in 2013–2014), 19 years at the first follow-up (in 2017–2018), and 23 years at the second follow-up (in 2021) (https://doi.org/10.17011/jyx/dataset/92452). Thus, the purpose of the study broadened, aiming also to identify longitudinal physical activity patterns from adolescence to young adulthood, and to examine the determinants, correlates, and health outcomes for the identified patterns.

At baseline, the participants were recruited through 156 sports clubs and 100 schools within six large Finnish cities (Helsinki, Jyväskylä, Kuopio, Oulu Tampere, Turku) and their rural surroundings (Kokko et al., 2015) (Figure 4). The sports clubs represented the ten most popular sports disciplines (both summer and winter sports, and both individual and team sports): basketball, cross-country skiing, floorball, gymnastics, ice hockey, orienteering, skating, soccer, swimming, and track and field. The adolescents who were not participating in any sports club were contacted through the schools.

The participants underwent the same procedure in all the data collection waves. They took part in electronic surveys on current health behaviours and health status. A subpopulation was also invited to participate in health examinations (also called pre-participation screenings) in one of the six national Centres of Excellence in Sports and Exercise Medicine. At baseline, the sample size for the health examinations was based on power calculations using information on asthma prevalence (population 8% vs. athletes 15%) (Kokko et al., 2015; Toivo, 2021).

The health examination included screening by a physician (after a medical history questionnaire), a pulmonary function test, blood pressure and body composition measurements, and a fasting blood sample. Written and oral instructions were also given on a hip-worn accelerometer, to be worn for seven consecutive days. In addition, the participants were asked to fill in a physical activity diary during the physical activity measurement week. More details of the health examination can be found in Kokko et al. (2015) and Toivo (2021).

The current doctoral study encompasses the HPSC study participants who took part in health examinations with valid accelerometry measurements from both measurement waves, at baseline (mean age 15) and at the first follow-up (mean age 19). The flow chart in Figure 4 describes the sample formulation in detail.

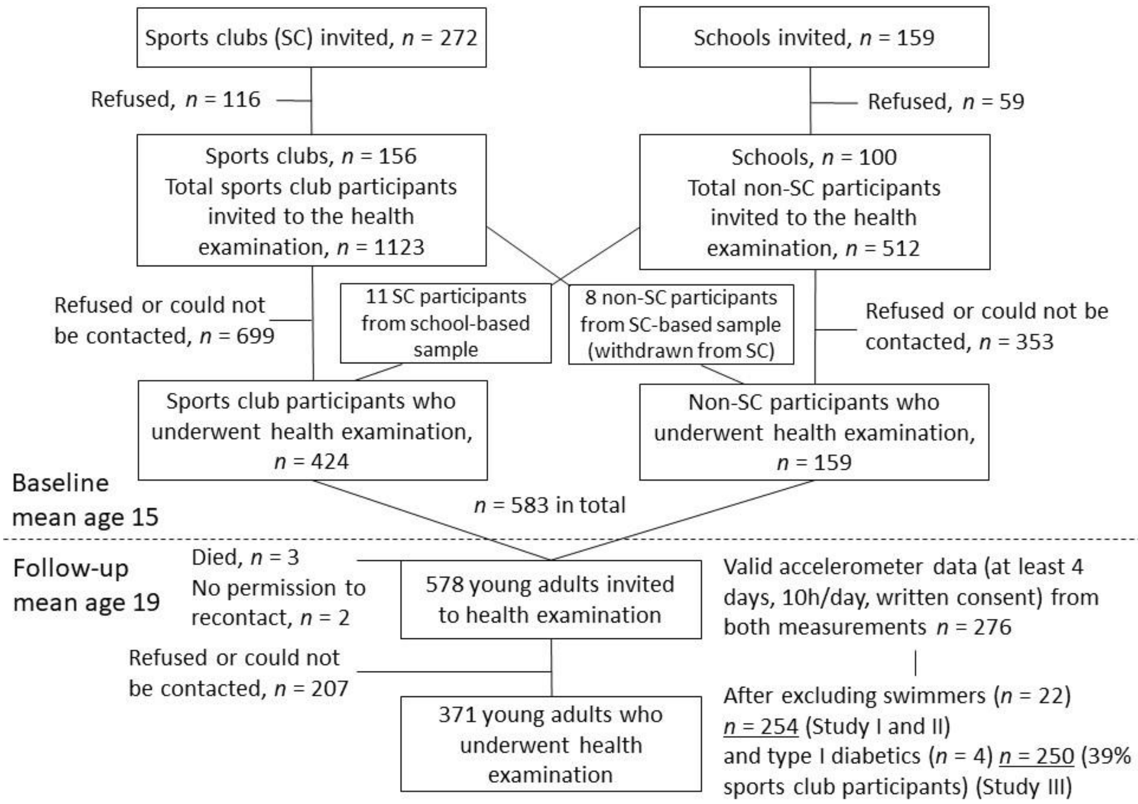


FIGURE 4 Flow chart of the data collection and study samples

4.2 Ethics

The HPSC study was conducted in accordance with the Declaration of Helsinki, and received ethical approval from the Ethics Committee of the Healthcare District of Central Finland (20.12.2012 (23 U/2012), 15.12.2016). Written consent was required from the participants, and also from a guardian when the participant was aged under 18. The permission notification included detailed information on the study, plus notification on the right of participants to refuse, and to withdraw their consent without giving a reason.

The HPSC study was conducted following the privacy policy for scientific research, which included privacy protection of the participants. The data were pseudonymized (including code numbers instead of names or identification data on the participants) and stored securely. The funders (Finnish Ministry of Education and Culture; Finnish Ministry of Social Affairs and Health) had no role in the study design, data collection, statistical analysis, or preparation of the study.

4.3 Measures

The study measurements are briefly presented in this section. A more detailed description is provided in the original publications and in Appendix 1 (the questions with response options).

4.3.1 Physical activity and sedentary time

Physical activity was measured by a hip-worn accelerometer (Hookie, AM20 Activity meter, Hookie Technologies Ltd., Helsinki, Finland), which collected and stored tri-axial data (the device includes three orthogonal measurement axes) as actual g-units (raw data) with a 100 Hz sampling frequency and 16 *g (gravity unit)* dynamic range. The Hookie accelerometer has been shown to be a valid measurement tool for both adolescents (Aittasalo et al., 2015) and adults (Vähä-Ypyä, Vasankari, Husu, Mänttäri, et al., 2015; Vähä-Ypyä, Vasankari, Husu, Suni, et al., 2015; Vähä-Ypyä et al., 2018).

The participants were instructed to wear the device for seven consecutive days during waking hours, except when bathing or during water activities. They were asked to report the time of wearing and taking off the device in the physical activity diary. The accelerometer was attached with an elastic belt on the right side of the hip at the level of the iliac crest. After the measurement week, the device was returned directly to the study personnel at one of the Centres of Excellence in Sports and Exercise Medicine (baseline data collection), or by mail in a prepaid envelope. Personal feedback from the measurement week was subsequently sent to the participants by mail.

The accelerometry data were analysed in units of 6 s duration and the analysis of the activity intensity was based on mean amplitude deviation analyses

(MAD), calculated from a resultant tri-axial raw acceleration signal, and converted to metabolic equivalents (METs) (Vähä-Ypyä, Vasankari, Husu, Mänttäri, et al., 2015; Vähä-Ypyä, et al., 2018). The conversion was based on previously analysed oxygen consumption (VO2) during a walking/running test with the same Hookie accelerometer and the standard conversion factor was used: 1 MET = 3.5 ml * kg * min (Vähä-Ypyä, Vasankari, Husu, Mänttäri, et al., 2015). The epoch-wise MET values were further smoothed by calculating the 1 min exponential moving average MET value for each epoch time point.

Light physical activity was defined as a MET value higher than or equal to 1.5 and less than 3.0 (with a MAD value between 22.5–91.5 mg), moderate physical activity as an MET value higher than or equal to 3.0 and less than 6.0 (MAD 91.5–414 mg). Vigorous physical activity was defined as an MET value higher than or equal to 6.0 (MAD over 414 mg) (Vähä-Ypyä, Vasankari, Husu, Mänttäri, et al., 2015; Vähä-Ypyä et al., 2018). The accuracy of the energy consumption estimation for the MAD method is about 1.2 MET for bipedal locomotion over a wide range of speeds (Vähä-Ypyä, Vasankari, Husu, Mänttäri, et al., 2015).

Separate analyses were conducted on activity without movement under 1.5 MET while seated or in a reclining/lying posture (to represent sedentary time, in line with Tremblay et al., 2017) and standing. Determination of the body posture was based on two facts, namely, that the earth's gravity vector is constant and that the body posture during walking is upright. The accelerometer orientation (in terms of the gravity vector during walking) was taken as the reference, and the angle for posture estimation (APE) was determined from the incident accelerometer orientation in relation to the reference vector (Vähä-Ypyä et al., 2018).

In the data preparation, a continuous quiescent time exceeding 30 minutes was taken to indicate non-wear of the device, as recommended also by others (Vanhelst et al., 2019). These non-wear periods were removed from the data. If the total accelerometer wear-time exceeded 18 hours per day, hours in excess of 18 were decreased from the sedentary time, as this indicated that the individual was wearing the device during sleep (1.3% of the measurement days of the participants in Studies I and II). For a valid measurement, at least ten hours per day and at least four days per week of the accelerometer data were required. Swimmers (n = 22) were excluded, because they were unable to use the device during their water activities.

4.3.2 Domains of physical activity

The information on the domains of physical activity – sports club participation, active commuting, and the amount of school physical education – was based on participants' self-reports via surveys.

Sports club participation (i.e. whether the person was participating in sports club activities) was confirmed in three separate surveys, in conjunction with a training diary. In Study I, a categorical variable, *change in sports participation,* was formed, based on the participants' responses at baseline and follow-up. The variable comprised four groups: 1) *never participated in sports club*; 2) *dropped out of sports club*; 3) *adopted sports club participation*; and 4) *maintained sports club* *participation*. Because of the small number of cases in the *adopted participation* category (n = 2), categories 3) and 4) were combined into a single category, i.e. *maintained or adopted sports club participation*. In Study II, participation in a sports club at baseline and follow-up was examined separately.

Similarly, a categorical variable on active commuting was formed in Study I. The categories were: 1) *never commuted actively*; 2) *stopped active commuting*; 3) *adopted active commuting*; and 4) *maintained active commuting*. The last two categories were combined. At baseline, the question assessed active commuting (walking or cycling) to school, and at follow-up active commuting to one's place of study or work. In Study II active commuting (*yes/no*) was examined separately at baseline and at follow-up.

Active commuting was assessed in more detail via questions estimating 1) trip length, i.e. distance to the school at baseline (or to the place of study / place of work at follow-up), 2) duration, and 3) mode of transport (Appendix 1).

The amount of school physical education (including any optional physical education) at age 15 was reported by the participants as total minutes. The information was treated as a continuous variable.

4.3.3 Health behaviours and psychosocial characteristics

The surveys assessed multiple health behaviours and psychosocial characteristics of the participants (see Table 5). Most of the survey questions were based on the international Health Behaviour in School-aged Children (HBSC) study (Currie et al., 2014). All the HBSC study questions have been piloted and validated at national and international levels (Currie et al., 2014), and many of the questions have been assessed for their test-retest reliability (Currie et al., 2014; Liu et al., 2010).

TABLE 5 Summary of the variables: health behaviours and psychosocial factors

Variable	Study	Classification	Reference
Alcohol consumption	II	1 = at least once a month 0 = less frequently or no consumption	SHP
	III	1 = weekly 0 = less than weekly or not at all	
Lifetime drunkenness	II	1 = two times or more 0 = never or once	HBSC
Snuff use	II	1 = less frequently to every day 0 = non-users	HBSC
Smoking	II	1 = daily to less than weekly 0 = non-smokers	HBSC
	III	1 = weekly 0 = less than weekly to not at all	

Variable	Study	Classification	Reference
Smoking or snuff use	III	1 = at least weekly 0 = less frequently to never	
Toothbrushing	II	1 = twice daily 0 = less than twice daily	HBSC, SHP
Breakfast eating on week-days	II	1 = 5 days per week 0 = 4 days or less per week	HBSC
School meals eating	II	1 = 5 days per week 0 = 4 days or less per week	created for this study
Energy drink consumption	II	1 = at least weekly 0 = never or less than weekly	HBSC
Fruit consumption	II	1 = daily 0 = never or less than daily	HBSC
Fruit and vegetable index	II, III	from 0 = no fruit and vegetable consumption to 14 = consumption of both at least once a day	HBSC, Vereecken et al., 2008
Sweets and sugared soft drinks index	II	from 0 = consuming both sweets and sugared soft drinks at least once a day to 14 = never eating sweets and sugared soft drinks	HBSC, Vereecken et al., 2008
Sleep duration on week-days	II	hours on average	created for this study
Feeling loneliness	II	1 = very often or often 0 = sometimes or never	HBSC
Weight satisfaction	II	1 = yes 0 = no	created for this study
Ease in talking to mother about things that really bother one (*also: father/ stepfather; at least one parent*)	II	1 = very easy or easy 0 = difficult or very difficult	HBSC
Exercising together with mother or stepmother (*also: father or stepfather; at least one parent*)	II	1 = sometimes to very often 0 = never to occasionally	created for this study

HBSC = Health Behaviour in School-aged Children study; SHP = Finnish School Health Promotion study

4.3.4 Other self-reported information

Sociodemographic characteristics, i.e. self-reported school grade average (only for adolescents), education and employment status and living arrangements (only for young adults), living area, and self-rated health were reported by the study participants in the health behaviour survey (Table 6). In addition, the assessment of family affluence was based on the adolescents' answers to survey questions on four common consumption indicators of material deprivation (cars, bedrooms, computers, vacations) (Boyce et al., 2006). A composite Family Affluence Scale score was calculated for each youth based on the individual's responses to these four items (see Appendix 1). The scale has previously been validated in the Health Behaviour in School-aged Children study (Boyce et al., 2006; Currie et al., 2014). To measure the stage of puberty, in the medical history questionnaire girls were asked at baseline about the onset of menstruation (for boys, see Section 4.3.5).

TABLE 6 Summary of the demographic (and some other) variables based on self-reports

Variable	Study	Categorization	Reference
Living area	I, II, III	1 = urban 0 = rural	HBSC
Education / employment status	I, II, III	1 = studying 2 = working 3 = other	created for this study
Study place	I, II, III	1 = general upper secondary school 2 = vocational school 3 = higher education institution	created for this study
Living arrangement	I, II, III	1 = living with parents 0 = living in any other way	created for this study
Self-reported school grade average	I, II, III	1 = grades 8–10 (good to excellent) 0 = grades <6.5–7.9 (poor to satisfactory)	created for this study
Self-rated health	I	1 = excellent to good 0 = fair to poor	HBSC
Onset of menstruation	I, III	1 = started 0 = has not started	created for this study

HBSC = Health Behaviour in School-aged Children study

4.3.5 Clinical examination

In the health examination, trained personnel (with a specialization in healthcare) measured the height and weight of the participants (without shoes, and wearing light clothes) to the nearest 0.5 cm and 0.1 kg, respectively. BMI was calculated as weight(kg)/height(m)^2. Blood pressure was measured via a validated, cuff-style oscillometric (automated) device (Pickering et al., 2005) while the participant was seated (after at least five minutes' rest). A second measurement was taken at an interval of one minute, and a third measurement was obtained if there was more than a 10 mm Hg difference in systolic or diastolic pressure between the first and second measurement. The average of two (or three) measurements was used in the analyses. The stage of boys' puberty (pubic hair stage) was assessed by a physician at baseline (Marshall & Tanner, 1970).

4.3.6 Laboratory analyses

Venous blood samples were taken after participants had fasted for at least ten hours. Serum and plasma were separated by centrifugation (2000 x g for 10 minutes) and stored at −75˚C prior to analysis. Concentrations of fasting plasma glucose, triglyceride, serum total cholesterol, HDL, and LDL cholesterol were analysed using standard enzymatic methods on a Cobas c702 clinical chemistry analyser (Roche Diagnostics, Basel, Switzerland). Serum insulin concentrations were determined using electrochemiluminescence technology on Cobas e801, according to the instructions of the manufacturer (Roche Diagnostics). All measurements were carried out in an SFS-EN ISO 15189:2013 accredited laboratory. Afterwards, the HOMA-IR was assessed via the formula: fasting serum insulin (mU/L) * fasting plasma glucose (mmol/L)/22.5 (Matthews et al., 1985).

4.4 Statistical analyses

Data analyses were performed using IBM SPSS Statistics (IBM, Armonk, NY, USA), versions 24 and 26, R software (R core team, Vienna, Austria) version 3.6.0 (R package KmL in Study I) and R Studio version 4.0.3 (in Study III, e.g. nlme package (Pinheiro et al., 2020)). The significance level was $p < 0.05$ in all the statistical tests.

4.4.1 Identifying longitudinal physical activity patterns

The longitudinal physical activity patterns were assessed via a data-driven method, i.e. the k-means algorithm for longitudinal data (KmL) (Genolini & Falissard, 2010). Data-driven methods can better identify genuinely heterogeneous physical activity patterns as compared to subjective methods, which establish the grouping of patterns by e.g. predetermined levels of activity or splitting into quartiles. The KmL was selected from the different data-driven clustering methods because it enabled longitudinal clustering for data with only two data collection waves over time.

The basic idea in the KmL was to group individuals following a similar progression of MVPA over time in such a way that the groups (clusters) were as different from each other as possible. The optimal solution was sought by: 1) determining the centre of each cluster (based on the Euclidean distance with Gower adjustment), and 2) assigning each observation to its nearest cluster (according to distance) (Genolini & Falissard, 2010). To find the optimal number of clusters and the best solution, the KmL was allowed to run for two to six clusters, 20 times each. The final solution was decided according to the following criteria: (i) the Calinski & Harabatz criterion (the optimal number of clusters is the number that maximizes the between-matrix variance and minimizes the within-matrix variance) (Genolini & Falissard, 2010). As the solutions for four and five clusters were almost equally good, the decision was also based on (ii) the number of participants in each cluster (for further statistical purposes at least 20 observations), and (iii) the amount of MVPA in the most inactive group (taken to be clearly under one hour per day at baseline). This made it possible to obtain meaningful comparisons between groups, bearing in mind that the recommendation for health-enhancing PA for children and adolescents is at least 60 min of MVPA on average per day (Bull et al., 2020). It is further in line with the common practice of validating cluster selection also by the researchers themselves (i.e. reasoning from the subject details) (Genolini & Falissard, 2010; Tang et al., 2017).

4.4.2 Analysing the descriptives

The differences between physical activity patterns were assessed via cross-tabulations followed by the Chi-square test or the Fisher's exact test for categorical variables, and via the Kruskal-Wallis test (with post hoc Dunn's test, adjusted by the Bonferroni correction for multiple tests) for continuous variables (Studies I, II, III). The significance of the changes over time was calculated by the McNemar test (categorical data) (Study I) and the Wilcoxon signed rank test (continuous data) (Studies I, III). The independent samples t-test and the Mann Whitney U test were performed in the loss-to-follow-up analysis (Studies I, III).

4.4.3 Modelling the correlates and determinants

Multivariable logistic regression analyses were used to examine the associations between selected background variables (i.e. possible correlates and determinants) and physical activity patterns. In other words, the patterns were treated as an outcome in the analyses. Missing cases were automatically excluded from these analyses.

In Study I, binary logistic regression analyses were conducted, including also the changes in the explanatory variables of physical activity domains and sedentary time (hence, for example, encompassing variables with three classes: 1) *active commuting maintenance/adopt*, 2) *withdrawal*, and 3) *never*, i.e. not commuting actively at age 15 or at age 19). Belonging to each of the patterns was modelled separately (except for treating activity maintainers and increasers as one combined group) with reference to all the other patterns together. The analyses were adjusted for the *change in the device wear-time* to eliminate the effect on the results of differences in usage time.

Multinomial logistic regressions were conducted in Study II to analyse the associations of health behaviours, psychosocial factors, and physical activity domains with physical activity patterns. Separate analyses were conducted for (i) baseline (measured at mean age 15) and for (ii) follow-up (measured at mean age 19) explanatory variables. Thus, determinants and longitudinal correlates, respectively, were searched for. The combined group of activity maintainers and increasers was set as the reference in the analyses. The models were adjusted for the *measurement interval* (age at the 2nd measurement minus age at the 1st measurement) and for the *change in device wear-time*.

In all the models, the explanatory variables were added via a forced entry method. The variable selection was based on univariable analysis, e.g. difference (p <0.1) between the physical activity patterns in cross-tabulations. Multiple different models (with different numbers of classes in categorical variables and different combination of explanatory variables) were tested and compared to find the best solution. The best solution was the one in which the number of zero cells was acceptable, and in which the test statistics were superior to other solutions (e.g. R^2 Nagelkerke, 2 log-likelihood).

4.4.4 Exploring the health outcomes

In Study III, the previously identified physical activity patterns were adopted as explanatory variables to study the difference between the physical activity patterns with regard to cardiometabolic risk factors. Linear growth curve models were conducted because the method enables a continuous outcome in a prospective study design. This means that the correlation (dependency) of repeated measurements within subjects is taken into consideration. The method allows variance between individuals according to both intercept and slope (random intercept, and time, i.e. change over time). In addition, growth curve modelling allows individuals to come from different groups, in this case from distinct longitudinal physical activity patterns.

Basically, the baseline level and slope (denoting the rate of change over time) for each cardiometabolic risk factor was explained by the physical activity pattern, sex, age, fruit and vegetable consumption, snuff and/or cigarette use, plus the change in the device wear-time between the baseline and follow-up measurements (to eliminate the effect on the results of differences in device usage time). The models included also the change in cardiometabolic risk factors over time by physical activity pattern, i.e. with time nested within the participant as a random effect.

In all the models, a multiple of the identity positive-definite matrix (PdIdent) was set as a correlation structure to improve the normal distribution of the residuals. Furthermore, the outcome variables triglyceride, HOMA-IR, and insulin were log-transformed using log(x+1) transformation for the same reason. In showing the results, backtransformation was used for clarification. Age was centred at 15, with age 15 corresponding to time = 0 to clarify the interpretations. Additional analyses were performed by adjusting the cardiometabolic risk factors also for BMI (centred) and the measurement season, in order to assess whether the associations were independent of BMI and seasonal variation.

5 OVERVIEW OF THE RESULTS

5.1 Sample characteristics

The study sample was 60% female, and at baseline (mean age 15) almost two thirds (62%) of the participants lived in families with high affluence[6]. At follow-up (mean age 19), most of the participants (69%) were still living with their parents. Half of the sample (49%) were studying in upper secondary education, while 13% of the participants were studying in higher education, and 21% were working (without simultaneous studying) during the follow-up measurement. Males, and those who reported lower school achievement, were more likely to not participate in the follow-up measurement (p <0.001).

The proportion of participants reporting distance of over 5 km between home and school (or to place of study or work at follow-up) increased over time (baseline 31%; follow-up 46%) (Table 7). Similarly, the proportion of participants commuting passively by use of a motor vehicle increased from baseline (43%) to follow-up (64%). At mean age 19, one-third (32%) of the participants drove a car to the place of study or work as their main mode of travel. The proportion of those reporting the duration of active commuting as 'none' increased over time (baseline 11%; follow-up 23%).

[6] The sample populations consist of exact numbers from Studies I and II (unless otherwise stated), while the sample in Study III was slightly smaller due to excluded participants with diabetes (n = 4).

TABLE 7 Characteristics related to active commuting to school at baseline and to the place of study or work (at follow-up), n (%)

	Baseline (*n* = 248)	**Follow-up** (*n* = 209–210)	***p***
Trip length from home			
≤ 1 km	52 (21)	28 (13)	0.004
1.1–3 km	77 (31)	48 (23)	(≤5 km; >5km)
3–5 km	42 (17)	38 (18)	
> 5km	77 (31)	96 (46)	
Duration of active commuting			
No active commuting at all	28 (11)	49 (23)	<0.001
<20 min /day	111 (45)	75 (36)	(none; any duration)
20–39 min/day	86 (35)	55 (26)	
40–59 min/day	15 (6)	24 (11)	
1 hour or more /day	8 (3)	7 (3)	
Mode of commuting			
On foot	62 (25)	30 (14)	<0.001
By bicycle	80 (32)	46 (22)	(by motor vehicle; on
Parent's car	20 (8)	12 (6)	foot or by bicycle)
By scooter, moped, or moped car	21 (9)	15 (7)	
By other motor vehicle	65 (26)	40 (19)	
By car that I drive myself	-	66 (32)	

Note: *p*-values were assessed using the McNemar test to analyse differences over time. At follow-up the frequencies included only those participants who were studying or working, and who responded to the questions (e.g. unemployed persons were not included). At baseline all the study participants were attending school; hence, the questions were addressed to all of them. The results comprise previously unpublished information.

5.2 Longitudinal physical activity patterns

Five longitudinal physical activity patterns were identified in Study I (Figs. 5 and 6), concurrently with an overall decline in participants' mean MVPA (Table 8). The most prevalent patterns were *inactivity maintainers* (*n* = 71) and *activity maintainers* (*n* = 70). Two distinct declining patterns were found: *decreasers from moderate to low physical activity* (*n* = 61), and *decreasers from high to moderate physical activity* (*n* = 32). In addition, the analysis revealed a small group of *increases (n* = 20), whose mean physical activity was at a high level already at baseline (MVPA 1h 50 min per day at age 15).

The background characteristics of the physical activity patterns showed no significant difference between the patterns regarding family affluence at baseline, or educational and employment status as young adults (Table 8). Moreover, the proportion of young adults still living with their parents did not differ between the patterns. However, there was a lower proportion of females among the *decreasers from high to moderate physical activity* (19%) as compared to the other patterns (e.g. 73% *of inactivity maintainers* were females).

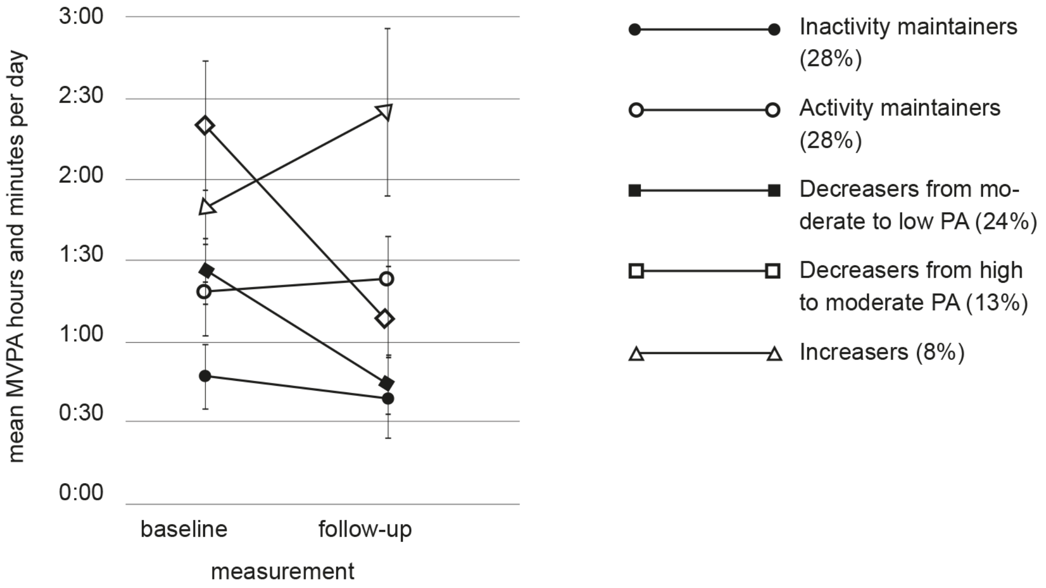


FIGURE 5 Longitudinal physical activity (PA) patterns (the data represent the mean and standard deviation)

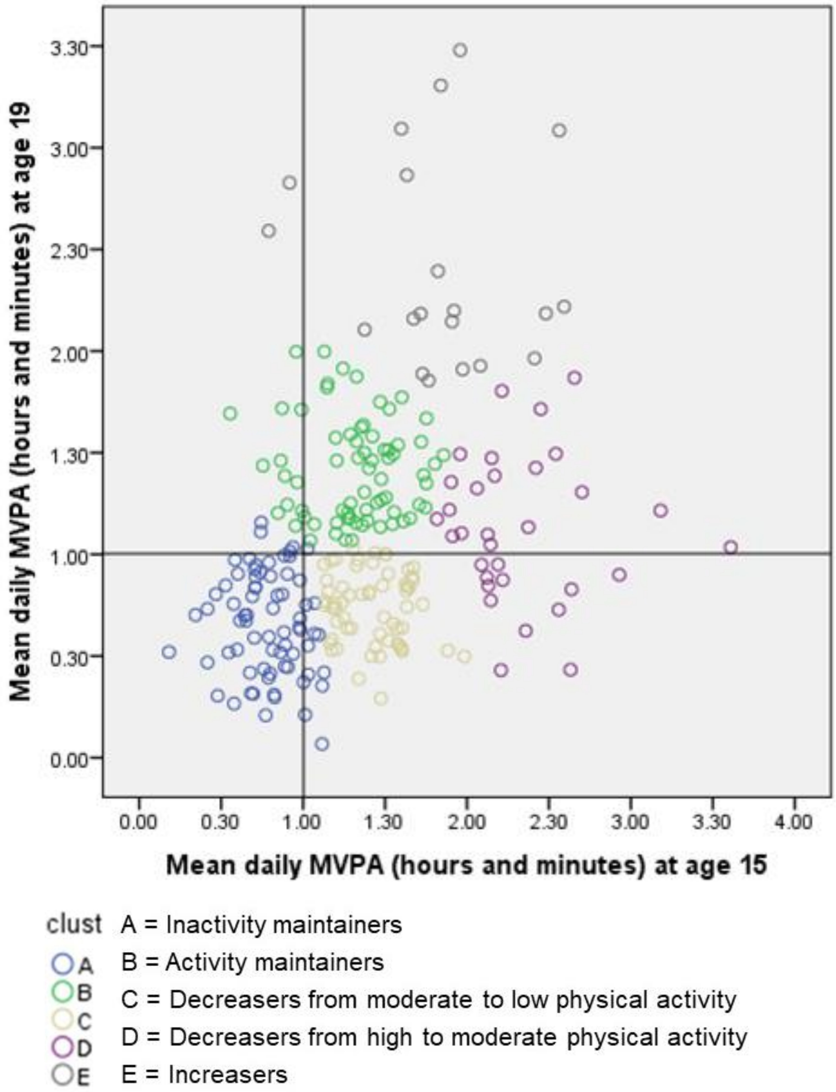


FIGURE 6 Scatter plot of the longitudinal physical activity patterns with lines showing the one hour per day guideline on aerobic physical activity for children and adolescents

TABLE 8 Background characteristics of the longitudinal physical activity patterns

	All	Inactivity maintainers (A)	Activity maintainers (B)	Decreasers from moderate to low PA (C)	Decreasers from high to moderate PA (D)	Increasers (E)	*p*
MVPA mean/day: hr:min (SD)							
baseline	1:22 (0:33)	0:47 (0:12)	1:19 (0:17)	1:25 (0:12)	2:20 (0:24)	1:50 (0:28)	[b]
follow-up	1:05[a] (0:34)	0:39 (0:15)	1:25 (0:15)	0:44 (0:11)	1:07 (0:21)	2:25 (0:31)	[c]
Age, mean years (SD)							
baseline	15.5 (0.6)	15.6 (0.5)	15.5 (0.6)	15.3 (0.5)	15.5 (0.5)	15.4 (0.5)	0.138
follow-up	19.4 (0.6)	19.4 (0.7)	19.4 (0.7)	19.2 (0.7)	19.5 (0.6)	19.5 (0.5)	0.130
Gender, females, *n* (%)	153 (60)	52 (73)	45 (64)	39 (64)	6 (19)	11 (55)	<0.001
High family affluence (baseline), *n* (%)	154 (62)	38 (56)	44 (64)	38 (62)	22 (73)	12 (60)	0.589
Living with parents (follow-up), *n* (%)	174 (69)	50 (70)	48 (69)	39 (64)	23 (72)	14 (74)	0.892
Education & employment status (follow-up), *n* (%)							
Studying	159 (63)	40 (56)	47 (67)	43 (71)	19 (59)	10 (53)	0.743[d]
in upper secondary school	100 (40)	23 (33)	29 (41)	28 (46)	13 (41)	7 (37)	
in vocational school	23 (9)	9 (13)	5 (7)	6 (10)	2 (6)	1 (5)	
in higher education	39 (16)	9 (13)	13 (19)	11 (18)	3 (9)	3 (16)	
Working	53 (21)	18 (25)	13 (19)	9 (15)	8 (25)	5 (26)	
Other	41 (16)	13 (18)	10 (14)	9 (15)	5 (16)	4 (21)	

Note: *p*-values were assessed using the Chi-square test or the Fisher exact test (in cases of sparse data) for categorical variables. The Kruskal-Wallis test was used in analysing differences in mean values between PA patterns cross-sectionally (post hoc Dunn's test adjusted by the Bonferroni correction for multiple tests). MVPA = moderate-to-vigorous physical activity; PA = physical activity; SD = standard deviation

[a] Significance over time $p < 0.001$. At age 15: 1 h 22 min = 9.7% of device wear-time; at age 19: 1 h 5 min = 7.9% of device wear-time

[b] A<B-E <0.001; B<D <0.001; B<E 0.004; C<D <0.001

[c] A<B,D,E <0.001; B>C <0.001; B<D 0.037; B<E <0.001; C<D,E <0.001; D<E <0.001

[d] The *p*-value represents the difference between the groups in bold font (studying, working, other) and PA patterns.

5.2.1 Characteristics via univariable analyses

5.2.1.1 Domains of physical activity

Inactivity maintainers reported less school physical education per week (mean 108 min) as compared to *increasers* (170 min), *activity maintainers* (144 min), and *decreasers from moderate to low physical activity* (143 min) (Table 9). Sports club participation and active commuting to/from school were prevalent among all the patterns at adolescence (mean age 15). On average, 57% of the adolescents commuted actively to school. Sports club participation differed between the patterns, varying from 41% of *inactivity maintainers* to 97% of *decreasers from high to moderate physical activity* at baseline.

Both active commuting and sports club participation decreased over time among all the patterns, apart from sports club participation among *increasers* ($p <$ 0.062). Withdrawal from active commuting was lowest (at 31%) among *inactivity maintainers*, and highest (at 63%) among *decreasers from high to moderate physical activity*. The prevalence of dropout from sports clubs did not vary with the pattern (mean 32%).

There were no differences between the patterns in duration of active commuting, trip length, or travel mode, either at baseline or follow-up (Appendix 2).

TABLE 9 Domains of physical activity by longitudinal physical activity patterns

		All	Inactivity maintainers (A)	Activity maintainers (B)	Decreasers from moderate to low PA (C)	Decreasers from high to moderate PA (D)	Increasers (E)	*Sig.*
School physical education at baseline, mean minutes (SD) (*n* = 239)		135 (67)	108 (51)	144 (79)	143 (62)	139 (67)	170 (55)	A < B,C * A < E ***
Sports club participation, *n* (%)								
baseline		176 (69)	29 (41)	51 (73)	47 (77)	31 (97)	18 (90)	***
follow-up		97 (38)	9 (13)	33 (47)	23 (38)	19 (59)	13 (65)	***
change [a]	never	76 (30)	41 (58)	18 (26)	14 (23)	1 (3)	2 (10)	***
	withdrawal	81 (32)	21 (30)	19 (27)	24 (39)	12 (38)	5 (25)	ns
	maintenance	95 (37)	8 (11)	32 (46)	23 (38)	19 (59)	13 (65)	***
	adopt	2 (1)	1 (1)	1 (1)	0	0	0	-
Active commuting, *n* (%)								
baseline		142 (57)	32 (47)	40 (58)	35 (57)	20 (67)	15 (75)	ns
follow-up [b]		76 (30)	17 (24)	25 (36)	20 (33)	6 (19)	8 (42)	ns
change [a]	never	78 (32)	30 (49)	22 (36)	18 (34)	5 (20)	3 (17)	*
	withdrawal	94 (38)	21 (31)	22 (32)	23 (38)	19 (63)	9 (47)	*
	maintenance	47 (19)	10 (16)	18 (29)	12 (23)	1 (4)	6 (33)	*
	adopt	27 (11)	6 (9)	7 (10)	8 (13)	5 (17)	1 (5)	ns

Note: *p*-values were assessed using the Chi-square test or the Fisher exact test (in cases of sparse data) for categorical variables. The Kruskal-Wallis test was used in analysing differences in mean values between PA patterns cross-sectionally (post hoc Dunn's test adjusted by the Bonferroni correction for multiple tests). * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; ns = non-significant; PA = physical activity; SD = standard deviation

[a] *p*-values were calculated comparing the frequency of the individual response category to each of the corresponding response categories for the other physical activity patterns (e.g. dropout vs. no dropout (= never+maintenance+adopt))

[b] The percentage distributions include also those not received the question (not working or studying) and thus interpreted as 'no active commuting to study place or work'.

5.2.1.2 Psychosocial factors

As shown in Table 10, there were differences between physical activity patterns in multiple psychosocial variables: loneliness, communication difficulties with father, exercise with parents, and weight satisfaction. Overall, when differences were observed between the patterns, the more active patterns tended to have a smaller prevalence of psychosocial complaints than the patterns involving less activity.

Loneliness was rarely reported at age 15 among all the patterns, but at age 19 differences were observed, insofar as 14% of *inactivity maintainers* and 16% of *decreasers from moderate to low physical activity* reported feeling lonely at least quite often, whereas none of the *decreasers from high to moderate physical activity* and *increasers* reported loneliness.

At baseline, difficulties in talking about troubling issues with one's father were more frequently reported by *inactivity maintainers* (43%) and by *decreasers from moderate to low* (45%) as compared to the other patterns (10%–23%). At follow-up, a similar tendency was observed. However, now also the *activity maintainers* (in addition to the *inactivity maintainers* and the *decreasers from moderate to low*) gave frequent reports of difficulties in talking with their father (44%), as compared to *increasers* (10%) and *decreasers from high to moderate* (17%).

Exercising together with a parent at least occasionally was less frequent among *inactivity maintainers* (57%) and *decreasers from moderate to low physical activity* (59%) at age 15 as compared to *increasers* (95%).

The prevalence of those satisfied with their weight was lowest among *inactivity maintainers* (baseline 67%; follow-up 59%). The prevalence differed significantly from the *increasers* and *decreasers from high to moderate*.

TABLE 10 Psychosocial characteristics compared between longitudinal physical activity patterns, n (%)

	Mean age	All	Inactivity maintainers	Activity maintainers	Decreasers from moderate to low PA	Decreasers from high to moderate PA	Increasers	*p*-value
Feeling loneliness quite often/often	15	15 (6)	6 (9)	4 (6)	2 (3)	2 (7)	1 (5)	0.778
	19	24 (10)	**10 (14)**	**4 (6)**	**10 (16)**	**0**	**0**	**0.017**
Ease of talking with mother	15	202 (82)	57 (84)	57 (84)	44 (73)	26 (87)	18 (90)	0.390
	19	208 (83)	57 (81)	54 (77)	49 (82)	30 (94)	18 (95)	0.182
Ease of talking with father	15	163 (68)	**38 (57)**	**49 (77)**	**33 (55)**	**26 (90)**	**17 (85)**	**<0.001**
	19	153 (64)	**41 (61)**	**37 (56)**	**34 (60)**	**24 (83)**	**17 (90)**	**0.012**
Ease of talking with at least one parent	15	209 (85)	58 (85)	61 (88)	46 (77)	26 (87)	18 (90)	0.434
	19	217 (86)	60 (86)	56 (80)	52 (85)	30 (94)	19 (100)	0.139
Mother[a] exercises or does sport with you at least occasionally	15	106 (43)	**27 (40)**	**35 (51)**	**20 (33)**	**10 (33)**	**14 (70)**	**0.020**
	19	88 (35)	**18 (26)**	**30 (43)**	**22 (36)**	**5 (16)**	**13 (68)**	**0.001**
Father[b] exercises or does sport with you at least occasionally	15	120 (48)	**21 (31)**	**38 (55)**	**25 (41)**	**17 (57)**	**19 (95)**	**<0.001**
	19	73 (29)	**16 (23)**	**24 (35)**	**15 (25)**	**7 (23)**	**11 (58)**	**0.024**
At least one parent exercises or does sport with you	15	162 (65)	**39 (57)**	**49 (71)**	**36 (59)**	**19 (63)**	**19 (95)**	**0.010**
	19	119 (47)	**30 (43)**	**40 (57)**	**29 (48)**	**7 (23)**	**13 (68)**	**0.006**
Satisfied with one's own weight	15	194 (77)	**46 (67)**	**51 (74)**	**47 (77)**	**31 (97)**	**19 (95)**	**0.002**
	19	179 (72)	**41 (59)**	**51 (73)**	**40 (69)**	**30 (94)**	**17 (85)**	**0.003**

Note: p-values were assessed using the Chi-square test or Fisher's exact test (in cases of sparse data) for categorical variables. The numbers in bold indicate significant differences. PA = physical activity

[a] Stepmother if mother does not live in primary home. [b] Stepfather if father does not live in primary home.

5.2.1.3 Health behaviours

Health behaviours did not differ between the physical activity patterns at age 15, apart from a slightly lower average sleep amount among *inactivity maintainers* as compared to *decreasers from high to moderate physical activity* and *increasers* (Table 11). At age 19, differences between the patterns were observed in smoking, as well as in fruit and/or vegetable consumption. One fifth of the *inactivity maintainers* and *decreasers from moderate to low physical activity* reported smoking at least sometimes, whereas none of the *increasers* smoked. Furthermore, one-third of the *inactivity maintainers* and *decreasers from moderate to low physical activity* reported eating fruits and/or vegetables at least daily. By contrast, half of the *activity maintainers* and *decreasers from high to moderate physical activity* reported daily fruit/vegetable consumption.

TABLE 11 Health behaviours compared between longitudinal physical activity patterns

	Mean age	All	Inactivity maintainers (A)	Activity maintainers (B)	Decreasers from moderate to low PA (C)	Decreasers from high to moderate PA (D)	Increasers (E)	*p*-value
Smoking, *n* (%)	15	14 (6)	6 (9)	3 (4)	5(8)	0	0	0.333
	19	34 (13)	**14 (20)**	**6 (9)**	**12 (20)**	**2 (6)**	**0**	**0.036**
Snuff use, *n* (%)	15	8 (3)	4 (6)	1 (1)	2 (3)	0	1 (5)	0.469
	19	25 (10)	6 (9)	4 (6)	7 (12)	7 (22)	1 (5)	0.155
Alcohol consumption at least once a month, *n* (%)	15	21 (9)	9 (13)	6 (9)	4 (7)	2 (7)	0	0.453
	19	167 (66)	45 (63)	49 (70)	36 (59)	24 (75)	13 (68)	0.533
Have been drunk at least twice, *n* (%)	15	25 (10)	11 (16)	8 (12)	3 (5)	2 (7)	1 (5)	0.268
	19	166 (66)	47 (66)	42 (60)	39 (64)	26 (81)	12 (63)	0.333
Eating a school meal every school day, *n* (%)	15	204 (82)	58 (85)	56 (81)	51 (84)	22 (73)	17 (85)	0.694
Eating breakfast every weekday morning, *n* (%)	15	165 (67)	42 (62)	48 (70)	40 (66)	21 (70)	14 (70)	0.866
	19	209 (83)	53 (76)	57 (81)	51 (84)	30 (94)	18 (95)	0.134
Daily consumption of fruits or/and vegetables, *n* (%)	15	110 (44)	26 (38)	36 (52)	23 (38)	15 (50)	10 (50)	0.348
	19	108 (43)	**23 (32)**	**37 (53)**	**21 (34)**	**18 (56)**	**9 (47)**	**0.035**
Fruit and vegetable consumption index, mean (SD)	15	9.1 (4.3)	8.0 (4.6)	9.9 (3.9)	8.5 (4.4)	10.6 (3.7)	10.0 (4.2)	ns
	19	9.3 (4.0)	**7.7 (4.2)**	**10.6 (3.6)**	8.7 (4.1)	**10.8 (3.0)**	10.0 (4.0)	**A<B,D****
Sweets and sugared soft drinks consumption index, mean (SD)	15	6.0 (3.5)	5.9 (3.6)	6.1 (3.5)	6.6 (3.2)	4.9 (3.4)	5.9 (3.5)	0.240
	19	7.2 (3.4)	7.1 (3.4)	7.2 (3.6)	7.3 (3.0)	7.7 (3.7)	6.7 (3.5)	0.915
At least weekly energy drink consumption, *n* (%)	15	20 (8)	8 (12)	4 (6)	4 (7)	2 (7)	2 (10)	0.721
	19	27 (11)	5 (7)	7 (10)	4 (7)	8 (25)	3 (16)	0.065
Brushing teeth two times per day, *n* (%)	15	158 (64)	44 (65)	45 (65)	40 (66)	19 (63)	10 (50)	0.769
	19	174 (69)	48 (68)	49 (70)	40 (66)	24 (75)	13 (68)	0.915
Sleep duration on weekdays, mean hours (SD)	15	8.2 (0.8)	**8.0 (0.8)**	8.3 (0.7)	8.3 (0.8)	**8.5 (0.6)**	**8.6 (0.8)**	**A<D,E***
	19	7.8 (0.9)	7.7 (0.9)	7.7 (1.0)	7.8 (0.9)	7.8 (0.8)	7.9 (0.6)	ns

Note: *p*-values were assessed using the Chi-square test or Fisher's exact test (in cases of sparse data) for categorical variables. The Kruskal-Wallis test was used in analysing differences in mean values between PA patterns cross-sectionally (with post hoc Dunn's test adjusted by the Bonferroni correction for multiple tests). Numbers in bold indicate significant differences. PA = physical activity; SD = standard deviation; * $p < 0.05$; ** $p < 0.01$

5.2.2 Characteristics via multivariable analyses

The simultaneous associations of multiple variables with longitudinal physical activity patterns were examined in Studies I and II. In Study I, the focus was on changes in the domains of physical activity and sedentary time (longitudinal correlates). In Study II, the focus was on the most significant differences between the physical activity patterns in 1) psychosocial factors, 2) health behaviours, and 3) domains of physical activity. These were explored separately for baseline predictors and follow-up correlates.

5.2.2.1 Change in domains of physical activity and sedentary time

The results showing the associations of change in physical activity domains and sedentary time with physical activity patterns are presented in Table 12. *Withdrawal from a sports club* (OR 0.3, 95% CI 0.2–0.6) and *maintained or adopted sports club participation* (OR 0.1, 95% CI 0.02–0.2) – as opposed to 'never'[7] participating in a sports club – were related to lower odds of belonging to the *inactivity maintainers* as compared to the other physical activity patterns (Table 12). Correspondingly, *maintained/adopted sports club participation* – as opposed to 'never' participating in a sports club (OR 3.6, 95% CI 1.8–7.4) – was associated with higher odds of belonging to the combined group of *increasers and activity maintainers*, as compared to the other physical activity patterns. Moreover, *withdrawal from a sports club* (OR 10.9, 95% CI 1.3–90.7) and *maintenance/adoption of sports club participation* (OR 11.2, 95% CI 1.4–90.0) – as opposed to 'never' participating in a sports club – were significant predictors for belonging to *decreasers from high to moderate physical activity*.

Maintained/adopted active commuting (OR 0.3, 95% CI 0.1–0.7) – as opposed to no such commuting either at baseline or at follow-up (i.e. 'never' commuting actively) – was associated with lower odds of being an *inactivity maintainer*. *Male gender* was associated with increased odds of being a *decreaser from high to moderate physical activity* (OR 7.4, 95% CI 2.6–21.3).

Decreased sedentary time (OR 0.96, 95% CI 0.93–0.98) was associated with higher odds of being in the combined group of *activity maintainers and increasers* as compared to other physical activity patterns (Table 12). Correspondingly, increased sedentary time was related to higher odds of being a *decreaser from moderate to low physical activity* (OR 1.05, 95% CI 1.01–1.07) and a *decreaser from high to moderate physical activity* (OR 1.04, 95% CI 1.001–1.1).

[7] Meaning neither at baseline nor at the follow-up measurement.

TABLE 12 Associations of gender, changes in sports club participation, active commuting, and sedentary time with physical activity patterns

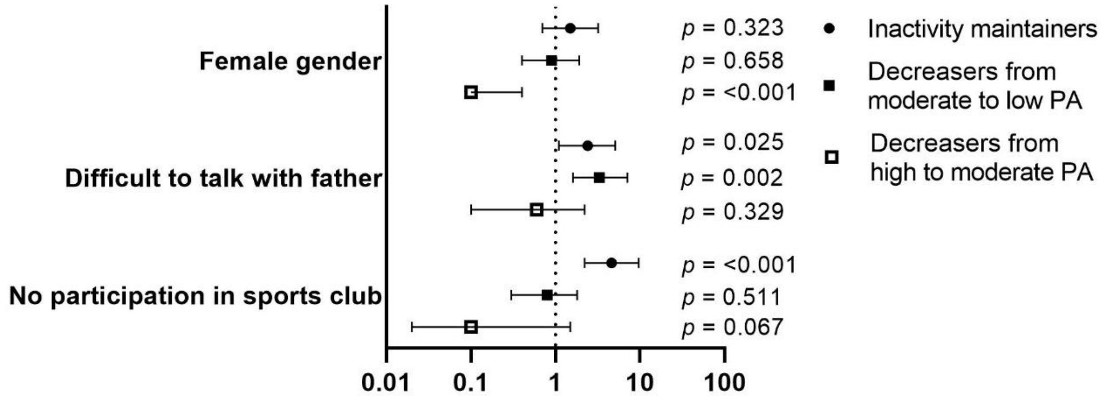
	Inactivity maintainers		Activity maintainers + increasers		Decreasers from moderate to low PA		Decreasers from high to moderate PA	
	OR (95% CI)	*p*	OR (95% CI)	*p*	OR (95% CI)	*p*	OR (95% CI)	*p*
Gender								
Male	0.5 (0.2–1.01)	0.055	0.8 (0.4–1.4)	0.376	0.8 (0.4–1.5)	0.400	**7.4 (2.6–21.3)**	**< 0.001**
Female	1.0		1.0		1.0		1.0	
Sports club participation								
Maintained or adopted	**0.1 (0.02–0.2)**	**< 0.001**	**3.6 (1.8–7.4)**	**< 0.001**	1.5 (0.7–3.3)	0.339	**11.2 (1.4–90.0)**	**0.023**
Withdrawal	**0.3 (0.2–0.6)**	**0.001**	1.2 (0.6–2.5)	0.625	1.9 (0.9–4.3)	0.097	**10.9 (1.3–90.7)**	**0.027**
Never[a]	1.0		1.0		1.0		1.0	
Active commuting								
Maintenance or adopt	**0.3 (0.1–0.7)**	**0.004**	1.7 (0.8–3.4)	0.165	1.5 (0.7–3.2)	0.343	1.3 (0.3–4.7)	0.744
Withdrawal	0.5 (0.2–1.03)	0.061	1.0 (0.5–2.0)	0.989	1.2 (0.5–2.5)	0.708	2.3 (0.8–7.3)	0.144
Never[a]	1.0		1.0		1.0		1.0	
Change in % of device wear-time by sedentary time	0.99 (0.96–1.02)	0.359	**0.96 (0.93–0.98)**	**0.001**	**1.05 (1.01–1.07)**	**0.004**	**1.04 (1.001–1.083)**	**0.046**

Note: Adjusted for change in the device wear-time. Statistically significant odds ratios are in bold. Binary logistic regression analysis: separately for each pattern vs. all the others together. PA = physical activity

[a] 'Never' means occurring neither at baseline nor at follow-up.

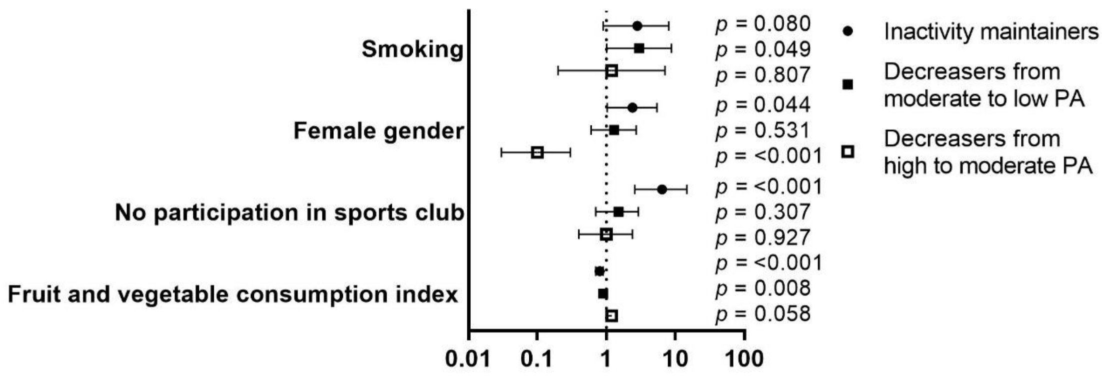
5.2.2.2 Psychosocial factors, health behaviours, and domains of physical activity

The most significant *predictors* (exposure variables from baseline measurements, i.e. determinants) for belonging to physical activity patterns are presented in Figure 7, and the best fitting longitudinal correlates (exposure variables derived from the follow-up measurements) are shown in Figure 8. Both models included *gender* and *sports club participation*. In addition, the predictor models included *communication difficulties with one's father,* and the model for longitudinal correlates included *fruit and vegetable consumption* and *smoking*.



Odds ratios (log-scale) with their 95% confidence intervals, calculated via a multinomial logistic regression analysis predicting belonging to longitudinal physical activity (PA) patterns. Comparisons of inactivity maintainers and decreaser groups with the combined group of activity maintainers and increasers. Adjusted for the measurement interval and the change in device wear-time between baseline and follow-up.

FIGURE 7 Logistic regression analysis based on exposure variables at baseline (mean age 15)



Odds ratios (log-scale) with their 95% confidence intervals, calculated via a multinomial logistic regression analysis determining correlates for belonging to longitudinal physical activity (PA) patterns. Comparisons of inactivity maintainers and decreaser groups with the combined group of activity maintainers and increasers. Adjusted for the measurement interval and the change in device wear-time between baseline and follow-up.

FIGURE 8 Logistic regression analysis based on exposure variables at follow-up (mean age 19)

Non-participation in a sports club (OR 4.6, 95% CI 2.2–9.6) and *communication difficulties with one's father* (OR 2.4, 95% CI 1.1–5.1) *at age 15* were associated with increased odds of being an *inactivity maintainer* as compared to membership of a group with favourable physical activity development. Furthermore, *communication difficulties with one's father at age 15* (OR 3.3, 95% CI 1.6–7.1) was related to belonging to the *decreasers from moderate to low physical activity*. *Male gender* was the only significant determinant for belonging to the *decreasers from high to moderate physical activity*.

Female gender (OR 2.4, 95% CI 1.03–5.4), *lower fruit and vegetable consumption* (OR 0.8, 95% CI 0.7–0.9), and *non-participation in a sports club at age 19* (OR 6.4, 95% CI 2.6–14.7) were associated with increased odds of being an *inactivity maintainer* as compared to belonging to the combined group *of activity maintainers and increasers*. A lower fruit and vegetable consumption index at age 19 (OR 0.9, 95% CI 0.8–0.97) was also related to being a *decreaser from moderate to low physical activity*. The same was true of smoking (OR 3.0, 95% CI 1.005–8.8).

5.2.3 Associations with cardiometabolic outcomes

Table 13 presents the differences in cardiometabolic risk factors at baseline and at follow-up, as analysed in Study III. Growth curve analyses were conducted with adjustments to examine the differences in cardiometabolic risk factors between the longitudinal physical activity patterns (Table 14). Significant differences were found both at baseline values and in the development of cardiometabolic outcomes over time when compared to the reference group of *inactivity maintainers*.

The *decreasers from moderate to low physical activity* had lower baseline values in insulin, HOMA-IR, and BMI when compared to the *inactivity maintainers* (Table 14, Figures 9–10). The *decreasers from high to moderate physical activity* had lower glucose, insulin, and HOMA-IR levels, and a higher HDL cholesterol concentration at baseline as compared to the corresponding levels among the *inactivity maintainers*. There was no significant difference in the baseline levels of any of the studied cardiometabolic risk factors between the *activity maintainers* and the reference group (i.e. *inactivity maintainers*), or between the *increasers* and the reference group (Table 14).

The development over time in insulin and in HOMA-IR levels among the *decreasers from moderate to low physical activity* differed from the corresponding development among the *inactivity maintainers*, thus showing increased insulin levels (vs. a decline among the *inactivity maintainers*), and unchanged HOMA-IR (vs. a decline among the *inactivity maintainers*) (Table 14, Figures 9–10). BMI increased among the *decreasers from moderate to low physical activity*, whereas BMI was unchanged (stable) among the *inactivity maintainers*.

The decline over time in systolic and diastolic blood pressure among the *increasers* differed from the stable trend among the *inactivity maintainers* (Table 14, Figures 9–10). There was no difference in the development of the cardiometabolic risk factors over time between the *activity maintainers* and the *inactivity maintainers*.

After adjusting the analyses for BMI, the results were generally similar to the original models. However, some associations no longer reached statistical significance, i.e. those pertaining to insulin and HOMA-IR at baseline among the *decreasers from high to moderate physical activity*, and the rate of change in insulin among the *decreasers from moderate to low physical activity* (see details from the original publication III). Adjustment for the measurement season did not alter the initial results (see details from the original publication III).

TABLE 13 Cardiometabolic risk factors at baseline and follow-up across physical activity patterns (mean (SD))

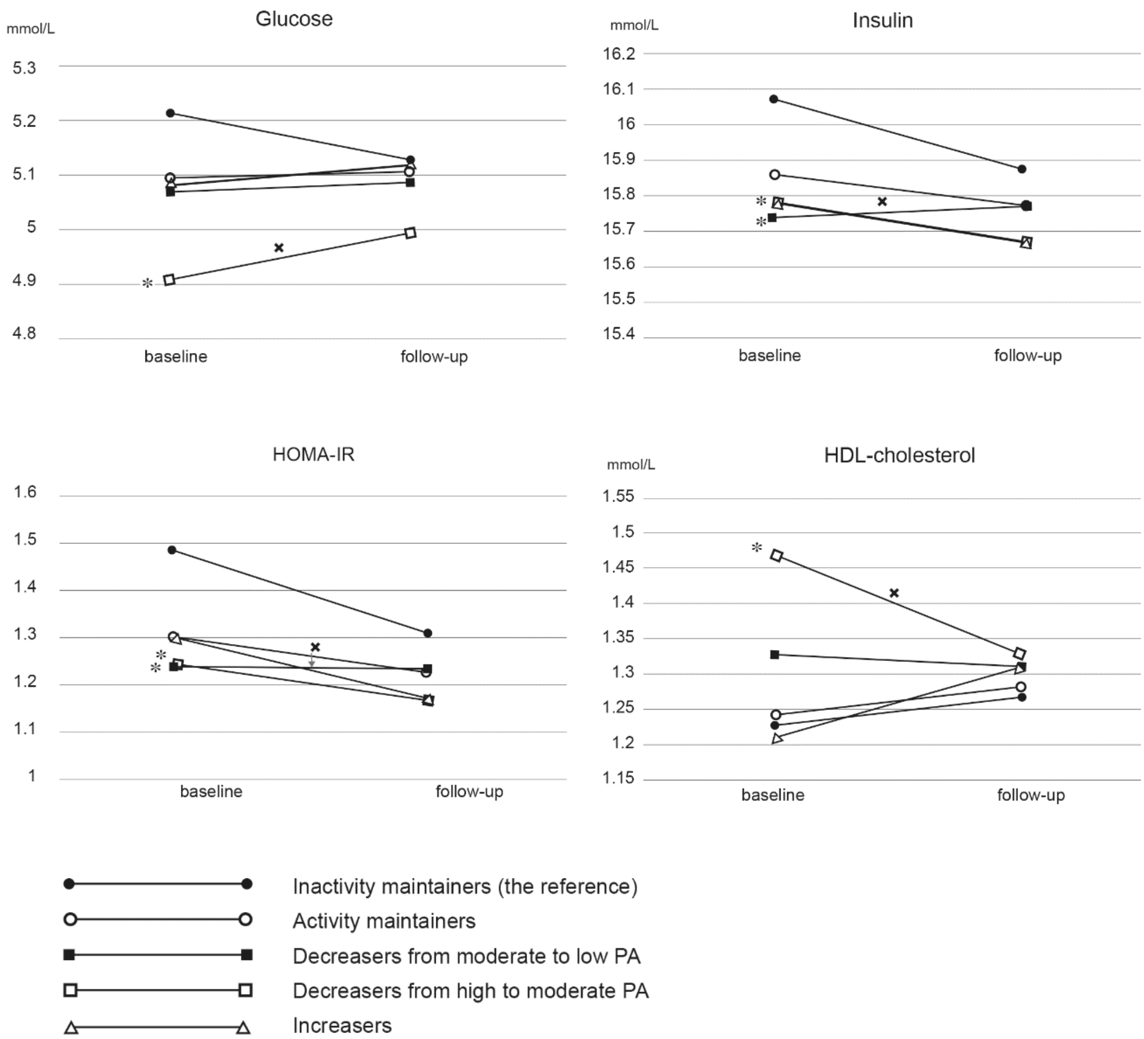
	All (women *n* = 144–150; men *n* = 95–100)		**Inactivity maintainers (A)**		**Activity maintainers (B)**		**Decreasers from moderate to low PA (C)**		**Decreasers from high to moderate PA (D)**		**Increasers (E)**	
	baseline	follow-up	baseline	follow-up	baseline	follow-up	baseline	follow-up	baseline	follow-up	baseline	follow-up
Glucose mmol/L	**4.94** (0.33)	**4.77***** (0.38)	**4.95** (0.28)	**4.68***** (0.33)	**4.93** (0.40)	**4.78*** (0.40)	**4.93** (0.32)	**4.79*** (0.38)	4.95 (0.29)	4.87 (0.40)	4.97 (0.25)	4.78 (0.36)
Insulin, mU/L	**11.42** (5.31)	**9.72***** (4.48)	**13.33** (6.55)	**10.56***** (5.23)	**11.42** (5.37)	**9.57*** (5.23)	10.73 (4.00)	10.50 (4.98)	**9.63** (3.66)	**7.82**** (2.38)	9.70 (4.01)	8.21 (4.40)
HOMA-IR	**2.53** (1.25)	**2.08***** (1.02)	**2.95** (1.53)	**2.22***** (1.15)	**2.53** (1.28)	**2.05**** (0.84)	2.37 (0.95)	2.27 (1.23)	**2.12** (0.82)	**1.69**** (0.52)	2.17 (0.98)	1.75 (0.93)
Cholesterol mmol/L	3.83 (0.67)	3.87 (0.79)	3.86 (0.70)	3.88 (0.76)	3.95 (0.76)	3.97 (0.83)	3.82 (0.58)	3.98 (0.82)	3.57 (0.59)	3.49 (0.73)	3.72 (0.53)	3.77 (0.58)
LDL cholesterol mmol/L	1.98 (0.58)	1.95 (0.64)	1.99 (0.62)	1.91 (0.61)	2.09 (0.64)	2.03 (0.64)	1.94 (0.54)	2.03 (0.71)	1.84 (0.51)	1.81 (0.65)	1.86 (0.41)	1.84 (0.50)
HDL cholesterol mmol/L	1.46 (0.30)	1.50 (0.35)	1.46 (0.38)	1.53 (0.38)	1.46 (0.32)	1.54 (0.36)	1.49 (0.28)	1.50 (0.33)	**1.41** (0.26)	**1.31**** (0.29)	1.47 (0.33)	1.59 (0.32)
Triglycerides mmol/L	**0.85** (0.40)	**0.92*** (0.45)	0.92 (0.44)	0.98 (0.45)	0.87 (0.40)	0.89 (0.51)	**0.79** (0.31)	**0.99**** (0.44)	0.72 (0.26)	0.82 (0.82)	0.87 (0.87)	0.77 (0.31)
Systolic BP mm Hg	**117.1** (10.89)	**121.2***** (11.89)	**116.4** (11.50)	**121.3***** (12.48)	116.6 (10.19)	118.5 (11.31)	**116.0** (10.69)	**121.9***** (11.78)	**120.3** (11.31)	**127.4**** (10.65)	119.4 (10.80)	118.4 (11.01)
Diastolic BP mm Hg	**67.4** (7.12)	**72.6***** (7.94)	**68.8** (6.17)	**74.4***** (8.60)	**67.5** (7.12)	**71.9***** (7.09)	**66.3** (6.77)	**73.7***** (7.45)	**66.2** (9.09)	**72.9***** (8.34)	66.7 (7.54)	65.7 (5.43)
Body mass index	**21.1** (2.82)	**23.2***** (3.32)	**21.8** (3.05)	**23.6***** (3.91)	**21.5** (2.90)	**23.4***** (3.41)	**20.4** (2.83)	**23.1***** (3.32)	**20.8** (2.08)	**23.0***** (1.86)	**20.5** (2.06)	**22.1***** (2.37)

Note: Numbers in ***bold** indicate significant differences over time* (analysed via the Wilcoxon Signed Rank test). The *cross-sectional differences in mean values between the patterns* were analysed via the Kruskal-Wallis test (with post hoc Dunn's test adjusted by the Bonferroni correction for multiple tests). The significant differences were: Insulin, baseline: D<A*; HOMA-IR, baseline: D<A*; Cholesterol, follow-up: D>B,C*; HDL cholesterol, follow-up: D<A,B,E*; Systolic BP, follow-up: A,E>D* & B>D**; Diastolic BP, follow-up: E<A,C***, E<B**, E<D*; Body mass index, baseline: C<A*. $^*p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$. Abbreviations: BP = blood pressure; HDL = high-density lipoprotein; HOMA-IR = homeostasis model assessment for insulin resistance; LDL = low-density lipoprotein; PA = physical activity.

TABLE 14 Growth curve models for cardiometabolic risk factors (assessing baseline level and change over time)

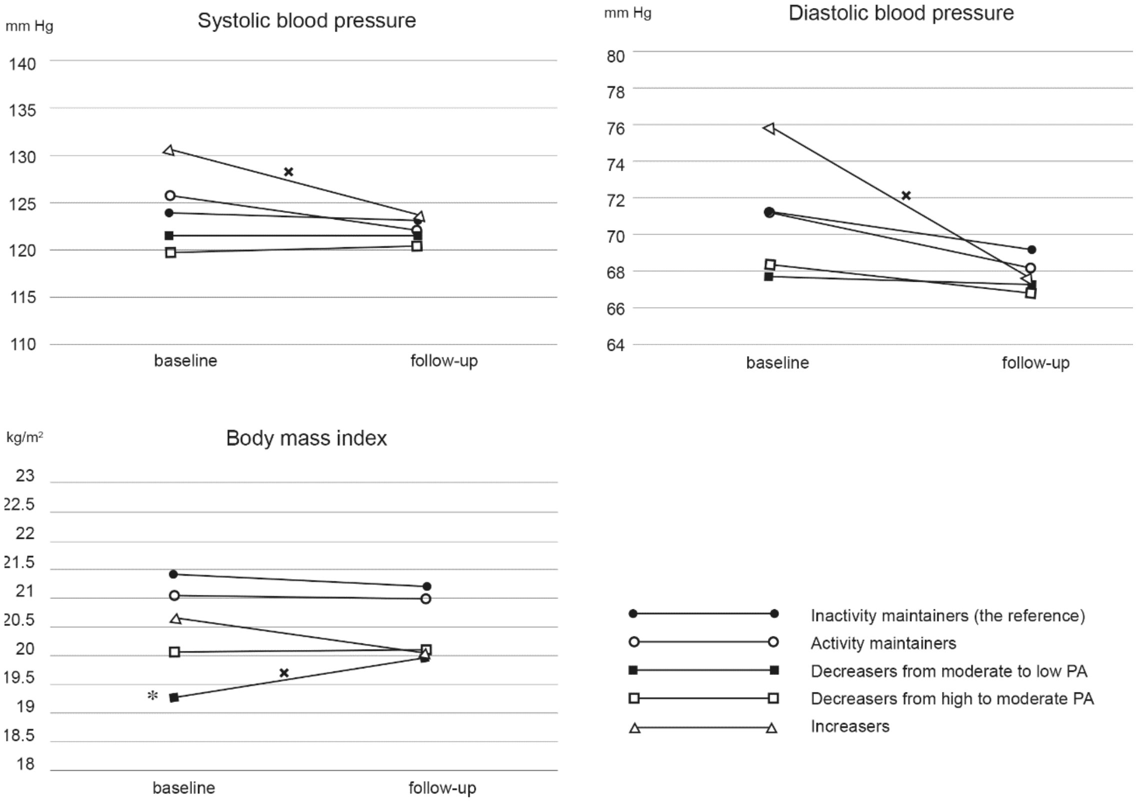
		Glucose (mmol/L)	Insulin (mU/L)†	HOMA-IR†	Cholesterol (mmol/L)	LDL cholesterol (mmol/L)	HDL cholesterol (mmol/L)	Triglycerides (mmol/l)†	Systolic BP (mm Hg)	Diastolic BP (mm Hg)	Body mass index
		β	β	β	β	β	β	β	β	β	β
Baseline level	Intercept	**5.22*** **	**16.07*** **	**1.48*** **	**3.77*** **	**2.10*** **	**1.23*** **	**0.89*** **	**124.13*** **	**71.28*** **	**21.39*** **
	PA pattern B	-0.12	-0.21	-0.19	0.10	0.09	0.01	0.005	1.82	0.06	-0.36
	PA pattern C	-0.15	**-0.33** **	**-0.25** **	-0.14	-0.12	0.10	-0.12	-2.38	-3.71	**-2.13** **
	PA pattern D	**-0.31***	**-0.29***	**-0.24***	0.05	-0.08	**0.24***	-0.10	-4.20	-3.00	-1.39
	PA pattern E	-0.14	-0.29	-0.18	-0.19	-0.22	-0.02	0.04	6.71	4.55	-0.76
	Sex (female)	**-0.23*** **	0.04	-0.01	**0.33*** **	0.13	**0.22*** **	0.01	**-12.02*** **	-1.21	-0.23
	Age (15 y)	-0.04	-0.003	-0.002	0.06	0.03	0.01	0.02	1.55	**2.03** **	**0.54***
Rate of change	Time	-0.09	-0.20	-0.18	-0.19	-0.17	0.04	-0.05	-0.85	-2.14	-0.22
	Time by PA pattern B	0.10	0.11	0.11	-0.001	0.02	0.002	-0.03	-2.91	-1.05	0.14
	Time by PA pattern C	0.11	**0.23***	**0.18***	0.13	0.13	-0.06	0.07	0.81	1.77	**0.90***
	Time by PA pattern D	**0.18***	0.09	0.10	-0.15	0.03	**-0.18** **	0.01	1.59	0.60	0.31
	Time by PA pattern E	0.13	0.08	0.03	0.08	0.09	0.06	-0.07	**-6.43***	**-6.72** **	-0.38

Note: Linear growth curve models, adjusted for change in the device wear-time, fruit and vegetable consumption, and weekly cigarette and/or snuff use. The *intercept* in the models represents the baseline level (mean) of the risk factor in the reference group (*inactivity maintainers*), when all the exposure variables are 0 – in other words, among men, at age 15 (since age was centred), and when fruit and vegetable consumption and weekly cigarette/snuff use were 0. *Time* represents the impact of time (mean slope) on the risk factors between baseline and follow-up in the reference group (*inactivity maintainers*). *Time by PA pattern* (B,C,D,E) represents the corresponding rate of change in the other physical activity patterns as compared to the rate of change in the reference group. Abbreviations: B = *activity maintainers*; BP = blood pressure; C = *decreasers from moderate to low physical activity*; D = *decreasers from high to moderate physical activity*; E = *increasers*; HDL = high-density lipoprotein; HOMA-IR = homeostasis model assessment of insulin resistance; LDL = low-density lipoprotein; PA = physical activity; β = unstandardized regression coefficients. The symbol † indicates back-transformation from the natural logarithm(log(x+1)). Numbers in bold indicate significant differences, *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.



Development over time of cardiometabolic risk factors across longitudinal physical activity patterns among non-smoking/non-snuff-using men with no fruit/vegetable consumption. Estimated using the parameters of the linear growth curve models after adjusting for the change in the device wear-time. The symbol * represents a statistically significant difference in the baseline level (intercept). The symbol × represents a statistically significant change over time (slope) as compared to the reference (inactivity maintainers). HDL = high-density lipoprotein; HOMA-IR = homeostasis model assessment of insulin resistance; PA = physical activity

FIGURE 9 Development over time of glucose, insulin, HOMA-IR, and HDL cholesterol across longitudinal physical activity patterns



Development over time of cardiometabolic risk factors across longitudinal physical activity patterns among non-smoking/non-snuff-using men with no fruit/vegetable consumption. Estimated using the parameters of the linear growth curve models after adjusting for the change in the device wear-time. The symbol * represents a statistically significant difference in the baseline level (intercept). The symbol × represents a statistically significant change over time (slope) as compared to the reference (inactivity maintainers). PA = physical activity

FIGURE 10 Development over time of blood pressure and body mass index across longitudinal physical activity patterns

6 DISCUSSION

This multidisciplinary study examined physical activity change and stability during the transition to young adulthood from two broad perspectives, as follows: 1) Distinct longitudinal physical activity patterns were identified. Thereafter, the characteristics (determinants and correlates) of the patterns were investigated, in relation to demographics, physical activity domains, sedentary time, health behaviours, and psychosocial factors. 2) The development of cardiometabolic risk factors was investigated between the patterns. In this way, information from the research fields of health promotion and sports and exercise medicine was combined, with the aim of aiding health promotion practices.

6.1 Physical activity does not decrease in adolescence for everyone: different patterns occur over time

The study found an average decrease in physical activity from adolescence to young adulthood, which is in line with previous studies (Corder et al., 2019; Farooq et al., 2020). Despite the average decline, there was large individual variation in the sample. The analysis identified five distinct physical activity patterns: (i) *inactivity maintainers* (28%), (ii) *activity maintainers* (28%); also two distinct declining patterns, (iii) *decreasers from moderate to low physical activity* (24%), and (iv) *decreasers from high to moderate physical activity* (13%). In addition, there was a small group of (v) *increasers* (8%), whose activity increased from an already high baseline level. Hence, in addition to the decreasing patterns, maintenance of low or high activity is common.

The large variation in the development of physical activity over the adolescent years was found also in previous studies, in which distinct groups of physical activity evolution over time were detected (Kwon et al., 2015a; Lounassalo, Salin et al., 2019; Rangul et al., 2011; Young et al., 2018; Zook et al., 2014). The studies varied in the amount and prevalence of the patterns, the methods used for physical activity measurement and pattern identification, and the sample characteristics (for example, the size and number of measurement points). The group of increasers detected in any study was small, with a prevalence varying between 7% and 12% (Rangul et al., 2011; Young et al., 2018; Zook et al., 2014). This finding is consistent with the findings of the present study.

6.2 The determinants and correlates of physical activity patterns

The study revealed considerable differences between the longitudinal physical activity patterns. These involved the development of physical activity domains and sedentary time, and further a number of health behaviours and psychosocial factors. Thus, distinctive characteristics were found for the patterns, although there was great variation between individuals.

The findings clearly show that sports club participation has a contribution in maintaining physical activity, including during early young adulthood. Notably, a lack of sports club participation throughout adolescence was related to higher odds of belonging to the *inactivity maintainers*. Sustained sports club participation, for its part, was associated with belonging to a combined group of *activity maintainers* and *increasers*, as well as *decreasers from high to moderate physical activity*. The results are consistent with the findings of previous studies showing a relationship between sports participation and maintained physical activity during adolescence (Kwon et al., 2015b; Rangul et al., 2011).

On the other hand, sports club participation did not guarantee sufficient physical activity for all adolescents, bearing in mind the physical activity recommendations for adolescents (Bull et al., 2020). In fact, as many as 41% of *inactivity maintainers* reported participation in a sports club at age 15. However, it should be noted that the young people in this group were by no means at the extreme end of spectrum of inactivity (having a mean MVPA figure of 47 min/day at age 15). They even fulfilled the physical activity recommendation for adults (Bull et al., 2020) at age 19 (i.e. a mean MVPA value of 39 min/day). Here, one can point to an apparent discrepancy in the guidelines, with 4.5 fewer hours per week of MVPA required for persons aged ≥18-year-olds than for those aged <18. This easily results in the situation found in the study, in which the guidelines may not be fulfilled at adolescence but 'sufficient' physical activity is reached at young adulthood (see also Espinoza et al., 2023; van Sluijs et al., 2021). Separate guidelines for young adults may be needed, bearing in mind also that the current guideline for 18-year-olds (Bull et al., 2020) is the same as for adults approaching retirement age.[8]

[8] It should be noted that most young people are unaware of the current physical activity guidelines (Vaara et al., 2019). Hence, it is unrealistic to expect that the recommendations per se would guide the behaviour of adolescents, in the absence of effective communication, policies, and efforts to create more supportive environment (Milton et al., 2020). This in no way detracts from the need to accumulate scientific evidence on the health benefits and risks pertaining to physical activity in different age groups.

Although sports club participation showed a range of associations with physical activity patterns, dropout from a sports club was common in all the patterns (with a mean of 32%). Similarly, the prevalence of active commuting declined over time – with a dropout prevalence varying from 31% of *inactivity maintainers* to 63% of *decreasers from high to moderate physical activity*. Thus, one can say that withdrawal from certain important physical activity domains, i.e. sports club participation and active commuting, is common among adolescents entering young adulthood. Previous studies from other countries have found either a declining or a stable trend in active commuting and organized sports among young people (Kemp et al., 2019). The declining tendency in these activities can be considered a challenge in aiming to achieve enough MVPA. It is notable that a review of previous studies (Campos-Garzón et al., 2023) found that almost half of the recommended amount of MVPA for adolescents may be achieved through active commuting.

This study and previous cross-sectional studies have shown longer distances to the place of study or work at young adulthood as compared to the distance to basic education (e.g. Kallio et al., 2021 cf. Turunen et al., 2023). The present study also showed that a third of the young adults commuted passively by driving a car themselves. Thus, longer distances may hinder active commuting, and a driving licence is likely to enable passive commuting in this transition phase. Even if one travels to school by motor vehicle, part of the trip may still be travelled actively. However, the prevalence of those reporting the duration of the active commuting as 'none' increased over time. This means that active commuting decreased when all parts of the travel were considered.

Withdrawal from a sports club may appear as a natural tendency in the life of adolescents who are entering adulthood, bearing in mind that there are many competing uses of time, including studies and social relationships. Indeed, the desire to concentrate more on studies has been reported as the most common reason for dropout (Rinta-Antila et al., 2023), despite the fact that those who continue in sports clubs generally show higher school performance than those who drop out (Rinta-Antila et al., 2023). Many other reasons for dropout have also been reported by young adults, with sports injury or illness being among the most common (Rinta-Antila et al., 2023). Furthermore, a prospective study has examined the differences between those continuing and those dropping out from a sports club. It appears that the odds of maintaining sports participation are increased by an early starting age for the main sport, entering national level competitions at adolescence, and having aims at age 15 to achieve success in competitions (Rinta-Antila et al., 2024). It should further be noted that adoption of sports club participation at young adulthood is rare (Rinta-Antila et al., 2023). It seems that although sports clubs reach a clear majority of children (71% of 11-year-olds) (Blomqvist et al., 2023), this no longer applies in young adulthood. Thus, according to the present study and a previous study (Mononen et al., 2021), only approximately one-third of persons aged 18–20 exercise in a sports club.

In the present study, *inactivity maintainers* turned out to be a group in which all the examined activity domains were less likely to occur. In addition to a higher risk of non-participation in a sports club and passive commuting as compared to the other physical activity patterns, the *inactivity maintainers* reported a lower level of school physical education – indicating a lower selection of optional physical education classes. Promotion of any of the studied physical activity domains might have potential for increasing total physical activity among this group of adolescents. However, physical activity is a complex behaviour, and an increase in one physical activity domain might result in a decrease in another domain.

Out of the health behaviours studied, lower consumption of fruits and vegetables, and smoking in young adulthood (though not yet at age 15) were related to unfavourable patterns in physical activity. Lower fruit and vegetable consumption was associated with increased odds of belonging to both *inactivity maintainers* and *decreasers from moderate to low physical activity*, with smoking also related to the decreaser group. Thus, some accumulation of unhealthy behaviours was observed, a finding similar in some respects to research findings in the past (Lounassalo, Hirvensalo, et al., 2019; Raitakari et al., 1994; Rangul et al., 2011). In our study, neither alcohol consumption nor binge drinking differed between the physical activity patterns; however, the results are consistent with previous studies insofar as (i) smoking seems to be related to unfavourable physical activity development over time (Raitakari et al., 1994; Rangul et al., 2011) and (ii) fruit and vegetable consumption is higher among persistently active people (Lounassalo, Hirvensalo, et al., 2019). The transition to young adulthood is undoubtedly an important life stage, bearing in mind that it is in this stage that the accumulation in unhealthy behaviours starts to appear.

Communication difficulties with one's father at age 15 were associated with increased odds of being a *decreaser from moderate to low physical activity* and also of being an *inactivity maintainer*. Hence, it seems that a father-adolescent relationship that supports open communication may be one determinant for sustained physical activity during adolescence. This is an interesting and new finding. However, it must be noted that the association disappeared when measurements were made at age 19. There is evidence that communication difficulties with parents pose a risk for life-satisfaction (Boniel-Nissim et al., 2015; Jimenez-Iglesias et al., 2017; Levin et al., 2012), but the links between parental communication and physical activity behaviour have received very limited attention in research. An exception was the study by Ornelas et al. (2007), who found that parent-adolescent communication predicted adolescent self-reported MVPA one year later, mediated by adolescents' self-esteem.

Generally speaking, communication with one's mother appears to be easier than with one's father according to the present study and earlier findings (Brooks et al., 2015; Inchley et al., 2020). Moreover, there has been a positive increasing trend in ease of communication with both parents over the 2000s (Brooks et al., 2015; Inchley et al., 2020). One can hope that this favourable trend continues in the future.

Feelings of loneliness at age 19 were more prevalent in *inactivity maintainers* (14%) and in *decreasers from moderate to low physical activity* (16%) as compared to *increasers* (0%) and *decreasers from high to moderate physical activity* (0%). Because frequent loneliness was non-existent in some physical activity patterns, the loneliness variable could not be fitted into the logistic regression models. The association found in cross-tabulation is logical also when one places it alongside a review study by Pels and Kleinert (2016). This study provides evidence for the potential diminishing effect of loneliness on physical activity – but conversely, the potential value of physical activity in reducing loneliness.

The physical activity patterns did not differ over the life situations studied, i.e. with regard to one's employment or educational status, or whether one was living with parents at age 19. Previously, moving out of the parental home has been linked either to 'no change' or to a decrease in physical activity (Gropper et al., 2020). The timing of moving out may be particularly important (see also Elder, 1998). In the study by Miller et al. (2019) in the USA, leaving the parental home between ages 19–31 and 25–36 was associated with decrease in activity but not if it happened in earlier, and probably more typical, life phase (between ages 11–18 and 19–31). In the present study, two thirds of the participants were still living with their childhood family, so this leaving-home event was not yet relevant to most of the young people studied. In Finland, young people leave their parental home on average at the age of 21.3, which is earlier than the average in EU countries (26.4) (Eurostat, 2023b).

In line with this, one should note that the transition to employment or higher education had not yet taken place for most of the participants. Moreover, among some who were working (without studying), this might have been a temporary phase, prior to entering into higher education. Based on a meta-analysis of studies encompassing mostly self-reported physical activity, leaving high school, or starting university is associated with a decrease in MVPA (Winpenny et al., 2020). Yet, overall, it is difficult to assess the true effect of certain life changes in relation to a change in physical activity when many simultaneous life events are occurring, along with other intervening factors (see also Winpenny et al., 2020).

Overall, the findings of this study illustrate the need to examine (i) longitudinal correlates, (ii) determinants (preceding the outcome of interest), and (iii) possible change in the correlates. Some health behaviours did not start to differ between the physical activity patterns until young adulthood, and this was also the case with feelings of loneliness. However, communication with one's father appeared to be more meaningful explanatory factor when it was studied as a predicting determinant (as opposed to longitudinal correlates studied at young adulthood). In addition, assessing *changes* in physical activity domains made it possible to reveal the role of sustained sports club participation in maintained physical activity, and how a lack of active commuting throughout adolescence was related to the persistence of low physical activity. All these examinations provide information that can be used to support health promotion practices (see Section 6.5).

6.3 Cardiometabolic health outcomes in relation to physical activity change and stability

The study provided new evidence on how different longitudinal physical activity patterns are associated with changes in cardiometabolic risk factors at adolescence (between ages 15 and 19). The results clearly showed that physical activity is important for health already at this early life stage. A favourable (declining) trend appeared in the systolic and diastolic blood pressure of adolescents whose physical activity increased over time, as compared to those who maintained a relatively low level of physical activity. Correspondingly, unfavourable changes in insulin and BMI emerged among *decreasers from moderate to low physical activity*, and in glucose and HDL cholesterol among *decreasers from high to moderate physical activity*. Hence, it seems that different changes in cardiometabolic risk factors may be expected in relation to (i) differing baseline physical activity levels and (ii) the magnitude of the change in physical activity. This is a novel perspective, and one that has not received much attention in previous well-conducted studies assessing the relationship between an overall decline in physical activity and cardiometabolic health consequences (e.g. Lehtovirta et al., 2023).

Only a few studies on device-measured physical activity during adolescence or young adulthood have explored cardiometabolic health outcomes in relation to distinct data-based physical activity patterns (Kwon et al., 2015a; Oh et al., 2021). The finding of the present study indicating an increase in BMI among *decreasers from moderate to low physical activity* is consistent with previous studies showing an increased accumulation of body adiposity (Oh et al., 2021) and obesity development (Kwon et al., 2015a) among groups displaying decreasing activity.

The levels of all the studied health outcomes were, on average, within the reference values for young people – including the levels for the group indicating sustained low activity. In this respect, the results suggest no immediate cause for concern. This could be expected, given that the study sample consisted mostly of relatively active young people. The results do, however, demonstrate physical activity effects on cardiometabolic health from adolescence to early adulthood (findings that are independent of sex, fruit and vegetable consumption, or cigarette/snuff use).

It was somewhat surprising that the *activity maintainers* and *inactivity maintainers* did not differ in any of the studied health outcomes, although the baseline values of HOMA-IR (a measure of insulin sensitivity) and insulin were close to significance. One could have expected that the baseline or follow-up levels of the risk factors would show a benefit from the maintenance of high physical activity, but this was not indicated in the study. One explanation might be that the reference group was not extremely passive. However, the result demonstrates that the cardiometabolic health consequences of both decreased and increased physical activity can be seen even when the reference group is that of young people who maintain a relatively low — but not extremely low — level of activity from adolescence to young adulthood. This can be regarded as a new and important finding.

6.4 Methodological considerations

The prospective cohort study data combining accelerometer-based physical activity measurements, surveys, and diverse cardiometabolic health outcomes – including also blood samples – formed a strong foundation for this study. Research of this kind covering the period from adolescence to young adulthood is rare also internationally (Agbaje 2023; Skrede et al., 2019), and unique in Finland.

It is typical that some participants are lost to follow-up in longitudinal studies, and this limits the reliability of the results. The participation rate of 63% in the HPSC study follow-up can be considered relatively high, since much lower participation rates have been observed in other studies. These include clinical examinations and accelerometer measurements, as in the UK biobank study with wrist-worn accelerometers (45%) (Doherty et al., 2017). Nevertheless, some degree of selection bias is possible in the study data; women and adolescents with higher school achievement were more likely to participate in the follow-up. In addition, selection bias in the recruitment phase is possible. In the HPSC study, 36% of those adolescents invited took part in the study baseline in which clinical examinations were conducted.

The study data are not representative of the entire Finnish population of the age cohort in question, due to the sampling through sports clubs and schools. Thus, sports club participation was more prevalent among the study population (69%) than in national survey estimates (41%) (Blomqvist et al., 2015). The participants were also somewhat more active than the average in Finland (Jussila et al., 2022). On the other hand, this was a strength, insofar as the data also allowed analysis of physical activity changes from high baseline levels. Moreover, the recruitment of participants was conducted from six different regions of Finland (from 100 schools and 156 sports clubs), which increased the geographical representativeness of the data. Similar cohort studies are usually limited to participants from smaller geographical area (Judice et al., 2020).

Another strength of this study was the use of accelerometry – which is the state-of-the-art method for assessing physical activity (Burchartz et al., 2020) – together with self-reports on activity domains. However, a 7-day physical activity measurement period might not be representative of the habitual behaviour of every participant, especially, when only two measurement points over the years were available. Additional time points might have revealed more fluctuations in physical activity during adolescence. Moreover, use of the device tends to underestimate the vigorous activities occurring in certain types of physical activity, such as weight training and skating (see also Toivo et al., 2023) – even though moderate and vigorous physical activity were combined in the analyses. Self-reports, for their part, are subject to recall bias, and were unable to capture, for example, different combinations of active commuting.

Longitudinal K-means clustering (Genolini & Falissard, 2010) enabled data-driven and thus more genuine identification of different decreased, increased, and sustained physical activity patterns, as compared to the subjective grouping of participants on the basis of some pre-determined levels (involving e.g. physical activity guidelines) or simple splitting into quartiles. There are also other methods available for data-driven grouping of longitudinal data, but no consensus exists on which method is best for detecting different patterns of change and stability. Some evidence suggests that KmL performs especially well when the sample size or number of measurement points is small (Gong et al., 2019). However, contrary opinions regarding the sample size have been put forward, stating that the growth mixture model has outperformed KmL even with small sample sizes (Den Teuling et al., 2023; Martin & von Oertzen, 2015). KmL is said to be a strong method that can complement latent class mixed modelling methods (Verboon & Pat-El, 2022), and it is also computationally less complex (Den Teuling et al., 2023; Verboon & Pat-El, 2022). On the other hand, group-based trajectory modelling has been preferred to KmL in some studies, for example when the data contains missing values, or when covariates are to be included in the trajectories (Den Teuling et al., 2023). However, for the purposes of this study, with data from two measurement points, the KmL was the most appropriate method. It should be noted that at least three measurement points are usually needed for other similar methods.

It should also be noted that the clustering methods do not accurately illustrate the development of each individual. Rather, averages at group level have been used. Moreover, a disadvantage of any method of classification is that the statistical power is inevitably reduced, in comparison with analyses in which physical activity is taken to be a continuous outcome or exposure. It is true that the aims of this study did not enable this kind of analysis, but a larger sample size might have prevented possible Type II error, with some non-significant results reaching statistical significance through having a bigger sample. Models conducted by logistic regression analysis, too, would have benefited from a larger sample size and thus narrower confidence intervals. It is also the case that in Study II, better identification of the *change* in the exposure variables (longitudinal correlates) would have been possible if the sample size had allowed that.

A strength of this dissertation is the utilization of growth curve modelling in the longitudinal dataset, as the method allowed variation between participating adolescents according to both intercept and slope. Little attention has so far been paid to *changes* in cardiometabolic risk factors between groups of young people with different physical activity patterns. It has been more common to examine the level of the health outcome only at follow-up (Howie et al., 2020; Oh et al., 2021; Rangul et al., 2012). Thus, this study helps to fill an existing research gap. Furthermore, *changes* in activity domains (considered as exposure variables) were explored in Study I, and this gives more information as compared to the traditional examination of physical activity correlates at a certain time point. The need to study also changes in the correlates of physical activity has been noted by others (Biddle et al., 2023).

A further strength in the analysis was the adjustment for other health behaviours (smoking/snuff use, fruit and vegetable consumption) in examining the associations between physical activity patterns and health outcomes. However, it was not possible to estimate, for example, participants' total energy intake (kilocalories) or saturated fat intake. These have an impact on e.g. cholesterol levels. In addition, the analyses did not include estimation of any indirect effects (mediators); nor did it include bidirectional analysis (e.g. between BMI and physical activity patterns).

The survey questions of this study were largely drawn from the international Health Behaviour in School-aged Children (HBSC) study, and the questions have thus been subject to validation (Currie et al., 2014). However, only one question assessed adolescents' communication with their parents. The inclusion of more questions would have increased the validity of the findings on this aspect. Future studies are needed to confirm the association between difficulties in talking with one's father and unfavourable development in physical activity.

A further limitation is the lack of information on all the physical activity domains. For example, apart from sports club participation, other organized leisure-time physical activities were not examined. Finally, there is a possibility that some important characteristics of the physical activity patterns (for example, at the environmental level) were not considered, and the results might have been different if these had been included.

6.5 Perspectives on health promotion

The present study highlights the need to acknowledge individual variation in physical activity during adolescence. The message 'more movement for all' cannot be considered a reasonable slogan, given that a large proportion of young people maintain their former sufficient level of activity, and some even increase their activity. Furthermore, the determinants and correlates vary between the different physical activity change and stability patterns, which further reinforces the view that *individual differences should be considered in health promotion*.

Physical activity has been described as a complex and dynamic behaviour (Biddle et al., 2023; Caspersen et al., 1985). However, the complexity has so far hardly been considered through the correlates applying to *diverging physical activity patterns*, although these differ from the correlates of physical activity at a given time point. Moreover, *the time-varying* nature of the possible correlates and determinants has rarely been examined (Biddle et al., 2023; Parker et al., 2021). In both research and practice, health promoters should pay attention to these aspects of physical activity behaviour. The findings are in line with notions from the life course approach (Elder et al., 2003; Sharma et al., 2023; Tones & Tilford, 2011, pp. 195–199), which assumes that life is not static, but rather in a constant flux of interaction with surroundings and linked lives. There are good reasons to acknowledge the variation over time in physical activity, and even separately for different domains of activity (e.g. active commuting, organized sports).

The individual variation and complexity in physical activity behaviour challenges health promotion efforts at the group or population level. The findings of this study offer elements to be included in targeted health promotion, for example by pointing out some of the unique characteristics of young people with unfavourably decreased activity or maintained inactivity. It should be noted that the actions intended to tackle maintained inactivity or decreased activity may at the same time support the maintenance of physical activity. Furthermore, the chosen approach can be primarily positive in nature – rather than 'corrective' – supporting the overall maintenance of an active lifestyle (hence involving *salutogenic orientation*) (Bauer et al., 2020).

The results of the present study suggest that forms of health promotion that does not actually refer to physical activity may be important in seeking to promote physical activity. The accumulation of unhealthy behaviours, and communication difficulties with one's father, were more prevalent among those young people with unfavourable development in physical activity. There is therefore good reason to support *open communication between offspring and parents, especially fathers*. This illustrates the point that the promotion of physical activity is not just a matter of sports policy, and should also involve other sectors of society (Ståhl, 2018; World Health Organization 2018, p. 43). The support for open communication and dialogue could be offered, for instance, in child health clinics, or any location where fathers are met. Moreover, the work done in health, education, social work, and in the voluntary sector would have possibilities to support the foundation of family communication, which forms part of overall wellbeing in families. In general, actions implemented at multiple levels (e.g. individual, social, environmental, and political) are considered to hold the greatest promise for achieving goals in physical activity promotion (Sallis & Owen, 2015; World Health Organization, 2018).

The health behaviours of young adults, including fruit and vegetable consumption and smoking, started to differ between the physical activity patterns at age 19. Hence, *the transition to young adulthood* is an important life phase in terms of the emergence of unhealthy behaviours. Health promotion efforts should thus be targeted at this life phase in addition to earlier efforts. Furthermore, it would be important to examine whether there are common underlying determinants for the accumulation of health-compromising behaviours (see also Ben-Shlomo et al., 2016). In this study, for example family affluence was not found to differ between the physical activity patterns.

The finding that loneliness is more frequent among young adults with unfavourable physical activity requires attention. Young adulthood is a peak period for mental health problems (Eurostat, 2023a) including loneliness (Victor & Yang, 2012), and young adults seem to be at risk for relative increases in loneliness (Baarck et al., 2021, p. 12). Thus, society needs to make greater efforts to tackle this challenge. Physical activity appears to be part of this issue, and should be addressed also from this perspective.

Young people face multiple life events and changes during their path towards young adulthood, and in the transitions from one setting to another.

Hence, this life stage deserves special attention. To support the maintenance of physical activity or the adoption of activities, the settings young people face in their everyday life should be viewed as opportunities for physical activities (see also Kokko & Baybutt, 2022; World Health Organization, 1986). The questions to be asked include the following:

1. Are educational organizations – before and during further education – up to date in terms of physical activity?
2. Are the impacts on physical activity through active travel taken into account when cuts are planned in the school network?
3. Are sports clubs willing to enable organized activities for young adults and for those who are adopting new exercise or sport disciplines?
4. Are there possibilities for commercial operators whose activities would promote physical activity for young adults?
5. What means do workplaces have to ensure the wellbeing and physical activity of young workers?
6. How does urban planning support forms of active travel to higher education, hobbies, and work?

The study gives indications that although dropout from a sports club is common during adolescence, organized sports still have a contribution in supporting favourable physical activity development when adolescents reach young adulthood. Thus, sports clubs deserve support from society, especially given that the activity is typically based on voluntary civic activities at local level (in Finland). In addition to this, there is a need for actions against dropout from sports clubs. It would be ideal if possibilities to join in organized sports at adolescence or young adulthood were available – these being in addition to competitive options.

There is also a need for opportunities to participate in sports with less time input, given that (i) studies take more time from a young adult's day than does basic education, (ii) the desire to concentrate on studies is an important reason for dropout (Eime et al., 2008; Rinta-Antila et al., 2023), and (iii) training in a sports club takes on average four training sessions out of the week of a person aged 16–20 year-olds' week (Mononen et al., 2021).

Overall, more emphasis should be given to developing sports clubs from the perspective of young adults and their needs. Looking beyond sports clubs, efforts should be made to ensure the availability of other forms of physical activities for young adults and to provide the relevant publicity, bearing in mind that not all sports clubs can offer organized sports for participants with non-competitive aims. Health promotion is not the core business of sports clubs, although it can sometimes be aligned with it (see also Dooris et al., 2022; Kokko, 2016).

Future interventions to promote young adults' active commuting should take into account the distances involved. Nearly half of the 19-year-olds in this study lived over 5km from their place of study or work. For those in this category, perhaps part of the travel could be walked, or active commuting could be pursued in other weekly journeys. A review of population-level interventions (among adults) suggests that a 'carrot-and-stick' approach could be adopted.

Thus, there would be a combination of both positive (promoting active travel) and negative strategies (discouraging vehicle use). This might be more effective than interventions that merely promote active travel (Xiao et al., 2022).

The present study showed that increasing physical activity was followed by favourable changes, and decreasing activity by unfavourable changes in cardiometabolic risk factors already during adolescence. This is a clear message which should be utilized by health promoters working with adolescents and advocating health policies. Many of the consequences of inactivity – such as type 2 diabetes and cardiovascular diseases – may be considered matters for the future, beyond the immediate concerns of adolescents. However, the present study has a different message: changes in physical activity are reflected in cardiometabolic risk *already in adolescence*. Thus, some concrete health benefits at the population level – as revealed by laboratory tests – can be expected at a young age.

6.6 Suggestions for future research

The possible correlates and determinants of longitudinal physical activity patterns could be related to any of the levels of the ecological model, i.e. intrapersonal, interpersonal, organizational, community, and public policy levels (see also Craggs et al., 2011). Thus, the correlates and determinants of physical activity change and stability during adolescence can be numerous, and they should be identified broadly, with attention also to the potential variation over time in the correlates (see also Biddle et al., 2023; Parker et al., 2021). Furthermore, the rarely studied level of public policy should be subject to intensive research. Researchers need to inquire into the consequences of political decisions as they affect physical activity over time. As noted in the Finnish two-year pre-primary education experiment (Sarvimäki et al., 2023)[9], it is possible to examine the consequences of experiments before making national decisions. Adding compulsory physical activity lesson to the secondary education curricula, or offering exercise vouchers to university students, are examples of experiments that could be conducted to examine the effects of such measures on young people's physical activity. Here it is worth noting that in vocational education, physical education currently does not exist as a separate subject.

There should be broader exploration of communication between parents and adolescents (which is a determinant at the interpersonal level of the ecological model) and the associations with physical activity development over time. Furthermore, more attention should be given to adolescents' perceptions of possibilities to talk with friends about things that really bother them, given that adolescence is typically a time when the importance of friends increases and that of

[9] As stated in Sarvimäki et al. (2023): '*The two-year preschool experiment is being implemented as a randomized field experiment in 148 municipalities. The experimental population comprises 35,000 children born between 2016 and 2017, randomly assigned into treatment and control groups*.' The effects of the two-year preschool experiment (as compared to a one-year preschool control) are due for evaluation in 2025.

parents somewhat decreases. Moreover, attention should be paid to overall family cohesion, and its possible relationship with physical activity change and stability.

At the community or organization level of the ecological model, future research could aim to develop sports clubs and other relevant settings for physical activity in young adults' lives. One possibility in this would be an intervention study based on young adults' needs, with the aim of decreasing dropout from sports clubs. It is notable also that research has so far largely neglected physical activity interventions targeting young adults' educational settings (van Sluijs et al., 2021), though a national intervention in Finland has been initiated to promote physical activity in tertiary education (Blom et al., 2018). On the other hand, as shown in this study, a large proportion of young adults live their lives outside education. Thus, there is a need for other contexts to reach young people. Overall, attention should be given to the proper planning of interventions (involving, for example, co-creation). This would encompass also implementation, and evaluation, which in turn should include process evaluation (involving fidelity, feasibility, and acceptability) (see also van Sluijs et al., 2021).

Given the lack of previous research, there is need to examine whether the findings from the present study are applicable to other populations. Device-based measurement of physical activity with larger samples would be preferable. Longitudinal studies taking into account both baseline physical activity and the change in physical activity in relation to the development in cardiometabolic health outcomes have been rare, and the matter requires further study. Research is needed from the perspectives of (i) average levels in adolescence, and (ii) longitudinal physical activity patterns.

The relations between physical activity and health outcome development during young adulthood and beyond should be studied also from the perspective of physical activity guidelines. It may indeed be possible or desirable to have new guidelines for young adults. In line with a previous study (Espinoza et al., 2023), the present study indicated that non-fulfilment of physical activity guidelines at adolescence easily changes to fulfilment of the recommendation at young adulthood. Other researchers, too, have criticized the existing guidelines as changing too rapidly as adolescents become 18-year-olds (van Sluijs et al., 2021).

A longer follow-up with the participants of this study could open up excellent opportunities for further information on physical activity development, encompassing correlates and determinants (including changes in domains or settings) and health outcomes during later young adulthood. The opportunities would include physical activity development in relation to forthcoming life events, educational and occupational changes, and the development of cardiometabolic risk factors. At the same time, topical health issues, including the increasing prevalence of obesity (Jääskeläinen et al., 2022) and mental health problems (Castelpietra et al., 2022), deserve more thoroughly study in relation to this understudied life phase. No such long-lasting cohort study has been conducted in Finland so far.

Any one of the identified physical activity patterns would be an interesting object for qualitative research, given that longitudinal qualitative studies have been relatively rarely conducted during this life phase (Agans & Lerner, 2024; Martins, et al., 2015; Takalo, 2016). For example, we do not know how the *decreasers from moderate to low physical activity* may perceive their life and the factors in it as playing a role in declining activity. Similarly, it would be valuable to analyse in depth those persons who constitute the *increasers*, and to discover whether we can learn something from their path.

From a methodological point of view, the data-driven trajectories of physical activity should be used in research also in the future, with different options compared to identify patterns. Going beyond this, to ensure sufficient statistical power, there is a need to apply other methods to investigate the development of physical activity over time with regards to health outcomes and determinants. When one uses continuous variables as a measure of physical activity over time, the comparison with other studies is easier than it is with group-based investigations based on heterogeneous groups. Of course, one then loses the advantages of group-based investigations, and behaviours that remain unchanged, for example maintained activity, are easily hidden.

7 MAIN FINDINGS AND CONCLUSIONS

1. Despite an average decline in physical activity from adolescence to young adulthood, large individual variation exists in the development of physical activity over time. Five patterns were identified: *inactivity maintainers* (28%), *activity maintainers* (28%), *decreasers from moderate to low physical activity* (24%), *decreasers from high to moderate physical activity* (13%), and *increasers* (8%).

   When planning health promotion practices, it is important to be aware of the variation in physical activity development during adolescence. 'More movement for all' is not a reasonable message for everyone.

2. The study identified the following characteristics pertaining to the physical activity patterns:

- ***Inactivity maintainers*** more frequently maintained passive commuting and more frequently reported a lack of sports club participation throughout adolescence, as compared to the other studied adolescents. They further reported the lowest amount of school physical education. In addition, it was more typical for *inactivity maintainers* to eat fewer fruits and vegetables and to report difficulties in talking with their father about issues that troubled them, as compared to those adolescents who maintained or increased physical activity over the years studied.

  Young people who maintain low physical activity throughout adolescence would benefit most from efforts aimed at increasing activity. There seems to be room for active commuting, but also for other physical activity domains. Organized physical activities should be arranged in a way that is suitable also for young people with little previous experience. Moreover, all the environments that young people face in their everyday lives – from routes available for active commuting to educational and occupational settings – should be seen as possibilities to accumulate physical activity. Families might benefit from actions that support open communication between adolescents and fathers, but further research is needed on this topic.

- Belonging to the ***decreasers from moderate to low physical activity*** was associated with increased sedentary time. Young people in this pattern were characterized by eating fewer fruits and vegetables. They were more likely to smoke as young adults, and to have more communication difficulties with their father at adolescence as compared to those who maintained or increased physical activity.

  Attention should be paid to the adoption and accumulation of unhealthy behaviours, including decreasing physical activity. Preventive efforts are needed when adolescents are transitioning to young adulthood. Activity decline may be prevented by health promotion that does not directly involve physical activity, such as support for open communication between adolescents and their fathers.

- Being a ***decreaser from high to moderate physical activity*** was related to male gender, increased sedentary time, and sustained sports club participation, but also to withdrawal from a sports club.

  Decreased activity and dropout from a sports club is not necessarily a negative evolution if the reduction in physical activity nevertheless ends up at a sufficient level of activity.

- ***Activity maintainers*** and ***increasers*** (combined) were characterized by decreased sedentary time and maintained sports club participation from adolescence to young adulthood. They reported fewer communication difficulties with their father as compared to *inactive maintainers* and *decreasers from moderate to low physical activity*. They also had more favourable health behaviours in terms of fruit and vegetable consumption and smoking, as compared to those adolescents who decreased their activity to a low level.

  Sports club participation supports sustained physical activity; it is an important setting for organized physical activity, and it deserves support from society. Suitable health promotion goals for this target group may be the maintenance of healthy behaviours, and an open discussion atmosphere in the family.

3. Participation in a sports club and active commuting to school is common among all the patterns at age 15 (active commuting = 47%−75%; sports club participation = 41%−97%). By age 19, a clear dropout from these activities is prevalent (mean for sports club withdrawal = 32%; active commuting = 31%−63%). For many, the distance to the place of study or work (at age 19) is longer than the distance to school (at age 15). Indeed, the distance is over 5 km for nearly 50% of the young adults.

To prevent dropout from sports clubs, it would be ideal if, in addition to competitive options, participation without competitive aims or with fewer time demands could be offered. This in line with the aim of developing sports clubs according to the needs of young adults. Furthermore, long distances to the place of study or work hinder the possibilities for active commuting. Hence, other options – such as walking part of the journey, or active commuting during other weekly journeys – should be studied and supported in the living environments of young adults.

4. The changes in physical activity are associated with cardiometabolic risk factors already between ages 15 and 19. A positive (decreasing) trend emerged in the systolic and diastolic blood pressure of adolescents whose physical activity increased over time, as compared to those who maintained a relatively low level of physical activity. Correspondingly, unfavourable changes in insulin and BMI occurred among *decreasers from moderate to low physical activity*, and in glucose and HDL cholesterol *among decreasers from high to moderate physical activity*.

   The results provide evidence for health promotion. Physical activity is beneficial for health. Decreasing activity relates to unfavourable changes in cardiometabolic risk factors even before the age of 20. Future studies should be aware of the possibility that different changes in cardiometabolic risk factors may be expected, in relation to (i) differing baseline physical activity levels, and (ii) the magnitude of the change in physical activity.

YHTEENVETO (SUMMARY IN FINNISH)

Liikkumisen muutos ja pysyvyys nuoruudesta nuoreen aikuisuuteen: selittävät tekijät ja yhteydet kardiometabolisiin riskitekijöihin

Fyysinen aktiivisuus (liikkuminen) keskimäärin vähenee nuoruudessa. Kaikkien nuorten liikkuminen ei kuitenkaan kehity samansuuntaisesti, sillä aktiivisuuttaan vähentävien lisäksi osa nuorista säilyttää entisen aktiivisuustasonsa, ja osa lisää liikkumistaan. Liikkumisen muutosta ja pysyvyyttä selittävät tekijät voivat olla erilaisia, mutta tutkittua tietoa niistä on toistaiseksi vähän. Myöskään liikkumisen muutosten yhteyttä elintapasairauksien riskitekijöihin ei tunneta kovin hyvin nuorilla. Tämän tutkimuksen tarkoituksena oli selvittää, miten terveyskäyttäytyminen, demografiset ja psykososiaaliset tekijät, liikkumisen muodot sekä paikallaanolo ovat yhteydessä eri suuntaisiin liikkumisen muutosryhmiin kuulumiseen 15 ja 19 ikävuoden välillä. Lisäksi tutkimuksen tavoitteena oli tutkia elintapasairauksien kehittymistä liikkumisen muutosryhmien välillä.

Tutkimuksen aineisto on osa Liikkumisen ja urheilun erilaiset polut – Terveyttä edistävä liikuntaseura (TELS) -seurantatutkimusta. Nuorten (n = 254) liikkumista mitattiin lantiolle kiinnitettävällä kiihtyvyysanturilla keskimäärin 15 ja 19 vuoden iässä, minkä lisäksi tutkittavat osallistuivat molemmilla mittauskerroilla paastoverikokeen sisältävään terveystarkastukseen ja vastasivat kyselyihin. Tutkittavat rekrytoitiin tutkimuksen alussa 156 liikuntaseuran ja 100 koulun kautta kuudesta kaupungista ja niiden lähikunnista eri puolilta Suomea. Liikkumisen muutosryhmät muodostettiin aineistolähtöisesti pitkittäisaineistojen K-means-klusterointimenetelmällä, ja ryhmien tyypillisiä piirteitä tarkasteltiin logistisen regressioanalyysin avulla (binäärinen ja multinomiaalinen). Elintapasairauksien riskitekijöiden kehittymistä tutkittiin lineaarisella kasvukäyrämallinnuksella vakioiden sukupuoli, ikä, mittarinpitoajan muutos sekä tutkittavien kyselyvastauksiin perustuva hedelmien ja vihannesten käyttö sekä tupakointi ja nuuskankäyttö.

Tulokset osoittivat, että liikkumisessa on paljon yksilöllistä vaihtelua nuoruudessa. Aineistosta muodostui viisi ryhmää: 1) aktiivisuuden säilyttäjät (28 %), 2) läpi nuoruuden vähän liikkuvat (28 %), 3) liikkumista keskitasolta alhaiselle tasolle vähentävät (24 %), 4) liikkumista korkealta tasolta keskitasolle vähentävät (13 %) ja 5) liikkumisen lisääjät (8 %). Liikuntaseuraharrastaminen oli vielä 15-vuotiaana varsin yleistä kaikissa liikkumisen muutosryhmissä (41–97 %), samoin koulumatkojen kulkeminen kävellen tai pyörällä (47–75 %). Nuoreen aikuisuuteen (19 v) mennessä moni lopetti liikuntaseuraharrastuksen (lopettajia keskimäärin 32 %) ja aktiivisen kulkemisen (31–63 % riippuen liikkumisen muutosryhmästä). Liikuntaseuraosallistuminen oli yhteydessä aktiivisuuden säilymiseen, kun taas passiivisesti sekä 15- että 19-vuotiaana kuljetut koulumatkat olivat yleisempiä läpi nuoruuden vähän liikkuvilla.

Keskusteluvaikeudet isän kanssa 15-vuotiaana ennustivat kuulumista sekä vähän läpi nuoruuden liikkuviin että liikkumista keskitasolta alhaiselle tasolle vähentäviin. Näissä liikkumisen muutosryhmissä myös hedelmien ja vihannesten käyttö 19-vuotiaana oli vähäisempää. Lisäksi liikkumista keskitasolta alhaiselle tasolle vähentävät tupakoivat tyypillisemmin 19-vuotiaana. Liikkumisen muutosryhmät eivät eronneet tutkittujen elämäntapahtumien, eli opiskeluun tai työelämään siirtymisen tai kotoa muuton suhteen. Paikallaanolo lisääntyi liikkumista vähentävissä ryhmissä ja vastaavasti väheni aktiivisuuden säilyttäjien ja liikkumisen lisääjien yhdistetyssä joukossa.

Liikkumisen lisääjien verenpaine laski, kun taas kehon painoindeksi, insuliini-, glukoosi- ja HDL-kolesterolipitoisuudet kehittyivät epäedulliseen suuntaan liikkumista vähentävissä ryhmissä (eri tavoin riippuen lähtötasosta ja liikkumisen muutoksen suuruudesta). Tulokset osoittavat, että fyysisen aktiivisuuden väheneminen on yhteydessä kardiometabolisissa riskitekijöissä tapahtuviin epäsuotuisiin muutoksiin jo alle 20 vuoden iässä. Samalla tulos perustelee liikkumisen tärkeyttä terveydelle jo nuorella iällä.

Koska liikkumisessa sekä liikkumisen muutosta ja pysyvyyttä selittävissä tekijöissä on paljon vaihtelua, tarvitaan kohdennettua terveyden edistämistä. Liikuntaseuraosallistuminen tukee aktiivisuuden säilymistä siirtymävaiheessa nuoreen aikuisuuteen, ja ansaitsee siksi tukea yhteiskunnalta. Olisi toivottavaa, että liikuntaharrastuksen aloittaminen seurassa olisi mahdollista myös myöhemmin nuoruudessa tai nuorena aikuisena ja että kilpaurheiluun tähtäävien vaihtoehtojen lisäksi tarjolla olisi ohjattua liikuntaa ilman suurempia tavoitteita. Kaikki arkiset elinympäristöt kävely- ja pyöräilyreiteistä opiskelu- ja työympäristöihin tulisi nähdä mahdollisuuksina edistää liikkumista ja kerryttää askelia ja muuta aktiivisuutta päivään. Laaja-alaisella terveyden edistämisellä, kuten isien ja nuorten vuorovaikutuksen tukemisella, saattaisi olla potentiaalia ehkäistä liikkumisen vähenemistä ja tukea aktiivisuuden säilymistä nuoruudessa. Fyysistä aktiivisuutta voidaan edistää myös toimenpiteillä, jotka eivät suoraan liity liikunnan tukemiseen tai tyypillisiin liikuntapoliittisen sektorin toimiin.

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Appendix 1. Survey questions used in the study

Theme	**Topic**	**Question**	**Response categories; Further information**	**Source; further information**
Demographics and other descriptive information	Family Affluence Scale (FAS)	1) Does your family own a car, van or truck? 2) Do you have your own bedroom for yourself? 3) During the past 12 months, how many times did you travel away on holiday with your family? 4) How many computers does your family own?	1) No *(=0)*; Yes, one *(=1)*; Yes, two or more *(=2)* 2) No *(=0)*; Yes *(=1)* 3) Not at all *(=0)*; Once *(=1)*; Twice *(=2)*; More than twice *(=3)* 4) None *(=0)*; One *(=1)*; Two *(=2)*; More than two *(=3)* A composite FAS score was calculated for each young person based on their responses to these four items. The two highest response categories ('2' and '3 or more') of the last two items (holidays and computers) were combined. Scores 6 or 7 indicated high family affluence	HBSC (mandatory question)
	Living area	What kind of place do you live in?	City, in the centre; City, outside the centre; Countryside, in the village centre; Countryside, outside the village centre	HBSC (country specific question)
	Education /employment status	*Follow-up* What is your main activity at the moment?	Studying; At work or entrepreneur; Laid off or unemployed; Military or non-military service; Maternity or parental leave; Other, what?	-
	Study place	*Follow-up: only for those reported studying* Are you currently studying at an educational institution? (if several, select the main educational establishment)	In a general upper secondary school; In a vocational institution (upper secondary school); At university of applied sciences; At university; In labour or employment training; In apprenticeship training; At open university or open university of applied sciences; Somewhere else, where?_______	-

Theme	**Topic**	**Question**	**Response categories; Further information**	**Source; further information**
	Living arrangement	*Follow-up* How do you currently live?	Alone; With my parents or a parent; With a roommate/in a cellular accomodation; With a married or cohabiting partner; With a married or cohabiting partner and a child or children together; Single parent with a child or children	-
	School grade average	*Baseline:* What was your school grade average (all subjects) in your last certificate?	<6.5; 6.5–6.9; 7.0–7.4; 7.5–7.9; 8.0–8.4; 8.5–8.9; 9.0–9.4; 9.5–10	-
	Self-rated health	Would you say your health is … ?	Excellent; Good; Fair; Poor	HBSC (mandatory question)
	Onset of menstruation	At what age did your menstruation begin?	____ years of age; ____ My menstruation hasn't started yet.	-
Active commuting	Distance to school	*Baseline:* How long is your distance to school? *Follow-up* …to place of study? (*for those reporting studying*) …to place of work? (*for those reporting working*)	less than 500 m; 500 m–1 km; 1.1–2 km; 2.1–3 km; 3.1–5 km; more than 5 km	Finnish Schools on the move (modified)
	Mode	How do you commute on your way to and from school at this time of year? (select the single most common option)	Walking; Cycling; By parent's car; By scooter, moped, or moped car; By other motorized vehicle *Follow-up:* *in addition to the previous* By car, I drive myself	Finnish Schools on the move (modified)

Theme	Topic	Question	Response categories; Further information	Source; further information
	Duration	*Baseline:* How long do you walk, cycle, or commute in other ways that require physical activity on school trips? *Follow-up*: …during study or work trips?	No active commuting at all; <20 min/day; 20–39 min/day; 40–59 min/day; 1 hour or more /day	Finnish Schools on the move, (modified)
Sports club participation	Sport club participation	*In the health behaviour survey:* Are you a member of a sports club?	*Baseline*: No; Yes, and I train in a sports club; Yes, but I don't participate in training *Follow-up:* No; Yes, and I participate in training; Yes, but I don't participate in training; Yes, I act as a coach or other club official; Yes, and I participate in training and act as a coach or other club official	HBSC (country specific question)
		In the sports injury and musculosceletal health survey: Are you involved in sports club activities?	Yes; No	-
School physical education	Amount	*Baseline:* How many minutes of school physical education do you have in a week? (calculate class physical education plus any optional physical education you do at school)	*Only numbers accepted*	-
Psychosocial factors	Loneliness	Do you ever feel lonely?	Very often; Often; Sometimes; Never	HBSC (mandatory question)
	Satisfaction with one's own current weight	Are you satisfied with your current weight?	Yes; No	-

Theme	Topic	Question	Response categories; Further information	Source; further information
	Ease of talking to parents	How easy it is for you to talk to the following persons about things that really bother you? Mark one option at each point. • Father • Stepfather (or mother's boyfriend) • Mother • Stepmother (or father's girlfriend)	Very easy; Easy; Difficult; Very difficult; I don't have or see this person	HBSC (mandatory question)
	Exercising together with a parent	During a typical week: How often does your mother (or your stepmother if your mother does not live in your primary home)* … Exercise or do sport with you? *father (stepfather) *(asked separately)*	Never; Seldom; Occasionally; Often; Very often	-
Health Behaviours	Frequency of alcohol consumption	On the whole, how often do you consume alcohol, for example a half-bottle of beer or more?	Once a week or more often; A couple of times a month; About once a month; Less frequently; I don't drink alcoholic beverages	Finnish School Health Promotion (SHP) study
	Lifetime drunkenness	Have you ever had so much alcohol that you were really drunk?	No, never; Yes, once; Yes, 2–3 times; Yes, 4–10 times; Yes, more than 10 times	HBSC (mandatory question)
	Snuff use	How often do you use snus at present?	Every day; Every week, but not every day; Less than once a week; I do not use snus	HBSC (country specific question)
	Smoking frequency	How often do you smoke tobacco at present?	Every day; At least once a week, but not every day; Less than once a week; I don't smoke	HBSC (mandatory question)

Theme	Topic	Question	Response categories; Further information	Source; further information
	Toothbrushing frequency	How often do you brush your teeth?	More than once a day; Once a day; At least once a week but not daily; Less than once a week; Never	HBSC (mandatory question)
	Frequency of eating breakfast on weekdays	How often do you usually have breakfast (more than a glass of milk or fruit juice)? Weekdays	I never have breakfast during the week; One day; Two days; Three days; Four days; Five days	HBSC (mandatory question)
	Frequency of eating school meals	*Baseline* How often do you usually skip school meals during a normal school week?	Not at all; I usually eat school meals; One day; Two days; Three days; Four days; Five days	-
	Food/drink consumption frequency	How many times a week do you usually eat or drink…? Fruits Vegetables Sweets (candy or chocolate) Coke or other soft drinks that contain sugar Energy drinks … *(the list continues)*	Never; Less than once a week; Once a week; 2–4 days a week; 5–6 days a week; Once a day, every day; Every day, more than once	HBSC (mandatory question)
	Sleep duration	How many hours on average do you sleep per night on weekdays? (from 22.00 to 07.00 = 9 hours)	________ hours	-

Note: HBSC = Health Behaviour in School-aged Children study. The HBSC study includes (i) mandatory, (ii) optional, and (iii) country-specific questions for the participating countries in conducting the survey (Currie et al., 2014; Paakkari et al., 2024).

Appendix 2. Characteristics of active commuting, compared between longitudinal physical activity patterns, n (%)

		All	Inactivity maintainers	Activity maintainers	Decreasers from moderate to low PA	Decreasers from high to moderate PA	Increasers	*p*-value
Trip length from home more than 5km	baseline	77 (31)	22 (32)	22 (32)	19 (31)	8 (27)	6 (30)	0.986
	follow-up	96 (46)	29 (51)	25 (42)	22 (42)	15 (56)	5 (33)	0.548
Motor vehicle the most common mode of transport:	baseline	106 (43)	36 (53)	29 (42)	26 (43)	10 (33)	5 (25)	0.161
	follow-up	133 (64)	40 (70)	35 (58)	31 (61)	21 (78)	6 (43)	0.141
Duration of active commuting: not at all	baseline	28 (11)	12 (18)	8 (12)	6 (10)	2 (7)	0 (0)	0.227
	follow-up	49 (23)	14 (25)	18 (30)	8 (16)	7 (26)	2 (13)	0.402

Note: *p*-values were assessed using the Chi-square test or Fisher's exact test (in cases of sparse data). PA = physical activity

ORIGINAL PUBLICATIONS

I

PHYSICAL ACTIVITY FROM ADOLESCENCE TO YOUNG ADULTHOOD: PATTERNS OF CHANGE, AND THEIR ASSOCIATIONS WITH ACTIVITY DOMAINS AND SEDENTARY TIME

by

Aira, T., Vasankari, T., Heinonen, O. J., Korpelainen, R., Kotkajuuri, J., Parkkari, J., Savonen, K., Uusitalo, A., Valtonen, M., Villberg, J., Vähä-Ypyä, H., & Kokko, S. P. 2021

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RESEARCH Open Access

Physical activity from adolescence to young adulthood: patterns of change, and their associations with activity domains and sedentary time

Tuula Aira[1*], Tommi Vasankari[2,3], Olli Juhani Heinonen[4], Raija Korpelainen[5,6,7], Jimi Kotkajuuri[8], Jari Parkkari[9], Kai Savonen[10,11], Arja Uusitalo[12,13], Maarit Valtonen[14], Jari Villberg[1], Henri Vähä-Ypyä[2] and Sami Petteri Kokko[1]

Abstract

Background: Longitudinal studies demonstrate an average decline in physical activity (PA) from adolescence to young adulthood. However, while some subgroups of adolescents decrease activity, others increase or maintain high or low activity. Activity domains may differ between subgroups (exhibiting different PA patterns), and they offer valuable information for targeted health promotion. Hence, the aim of this study was to identify PA patterns from adolescence to young adulthood; also to explore the associations of (i) changes in PA domains and in sedentary time, (ii) sociodemographic factors, and (iii) self-rated health with diverging PA patterns.

Methods: The observational cohort study data encompassed 254 adolescents at age 15 and age 19. K-means cluster analysis for longitudinal data was performed to identify participant clusters (patterns) based on their accelerometry-measured moderate-to-vigorous PA (MVPA). Logistic regressions were applied in further analysis.

Results: Five PA patterns were identified: *inactivity maintainers* ($n = 71$), *activity maintainers* ($n = 70$), *decreasers from moderate (to low) PA* ($n = 61$), *decreasers from high (to moderate) PA* ($n = 32$), and *increasers* ($n = 20$).
At age 15, participation in sports clubs (SC, 41–97%) and active commuting (AC, 47–75%) was common in all the patterns. By age 19, clear dropout from these activities was prevalent (SC participation mean 32%, AC 31–63%). Inactivity maintainers reported the lowest amount of weekly school physical education.
Dropout from SC – in contrast to non-participation in SC – was associated with higher odds of being a decreaser from high PA, and with lower odds of being an inactivity maintainer. Maintained SC participation was associated with higher odds of belonging to the decreasers from high PA, and to the combined group of activity maintainers and increasers; also with lower odds of being an inactivity maintainer. Maintenance/adoption of AC was associated with decreased odds of being an inactivity maintainer. Self-reported health at age 19 was associated with the patterns of maintained activity and inactivity.

(Continued on next page)

* Correspondence: tuula.m.aira@jyu.fi
[1]Faculty of Sport and Health Sciences, Research Centre for Health Promotion, University of Jyväskylä, PL 35, FI-40014 Jyväskylä, Finland
Full list of author information is available at the end of the article

(Continued from previous page)
Conclusions: PA patterns diverge over the transition to adulthood. Changes in SC participation and AC show different associations with diverging PA patterns. Hence, tailored PA promotion is recommended.

Keywords: Physical activity, Sports, Adolescence, Young adults, Longitudinal studies, Sedentary behaviour, Accelerometer

Background

Longitudinal studies have shown that physical activity (PA) declines from adolescence to young adulthood [1]. These results, which are based on *population-level averages*, mask individual variation, with some subgroups of young people increasing or decreasing PA, and others maintaining (in)activity. In recent years, it has thus become more common to identify distinct PA patterns[1] in efforts to gain more specific information on PA evolution over time [2, 11, 12]. For example, using accelerometry to measure moderate-to-vigorous PA (MVPA) at ages 5–19, Kwon et al. [13] identified four trajectories, namely *consistently inactive* (15%), *consistently active* (18%), *decreasing moderate PA* (53%), and *substantially decreasing high PA* (14%). In some studies, a subgroup of PA *increasers* has been further identified, with a prevalence varying between 7 and 14% [2, 3, 7].

It is important to identify PA development over time and to further characterize PA patterns in order to gain more information for targeted and evidence-informed health promotion [4, 10, 11, 14]. Determinants at many levels – including individual, social, environmental, and policy-related – may predict PA change over time [15] and e.g. declined PA may be explained by different factors from those relevant to sustained inactivity [11]. Information on these differing determinants may be useful in planning PA promotion interventions while taking into account the distinct forms of PA evolution during the transition to young adulthood. So far, studies have been conducted on the associations of various determinants and correlates with PA change patterns during adolescence, focusing on e.g. BMI [3, 7, 12], maturity [12], health behaviours [3, 7], parental PA [3], education [3, 12], socioeconomic status [16], and support for PA [7].

Considered as a PA domain (i.e. the context in which PA occurs) [17], *organized sports participation* has been related to different PA patterns [3, 13]. However, only a few prospective studies have explored the simultaneous evolution of several domains of PA over time [17, 18], and no studies have aimed to assess comprehensively the multiple domains of PA and the changes within them in order to identify differences between PA patterns (e.g. observing whether withdrawal from active commuting (AC) and sports club (SB) participation is associated with a pattern of declining activity). Nor has measured sedentary time been included in the analyses of the determinants and correlates of PA change patterns. It can be claimed that both PA and sedentary behaviour measurements are needed, bearing in mind that young people can engage in considerable sedentary time and PA on the same day [19].

So far, few studies have examined PA change and maintenance during the transition to young adulthood on the basis of measured PA rather than self-reported PA [1, 11]. The aims of this longitudinal study were:

1) to identify *PA change patterns* from adolescence to young adulthood (also characterizing the groups further by distributions of different intensities of PA and sedentary behaviour),
2) to explore how changes in PA domains and in sedentary time are associated with diverging PA patterns. (The domains analysed were *sports club participation, active commuting*, and the *amount of school physical education* (assessed only at age 15)).
3) to examine how sociodemographic factors and self-rated health are associated with diverging PA patterns.

Methods

Study sample

This observational cohort study encompassed adolescents who participated in the *Health Promoting Sports Club* (HPSC) study at ages 15 (i.e. in 2013–2014) [20] and 19 (i.e. as young adults, in 2017–2018). At baseline, the participants were recruited from (i) 156 sports clubs representing the ten most popular sports in Finland; (ii) 100 schools (pupils both with and without SC participation) from six large cities and surrounding communities in different parts of Finland [See Additional file 1, described in detail in [20]].

The recruited individuals initially completed two internet surveys on health behaviour and on musculoskeletal health. Pre-participation screening was then conducted on randomly selected respondents based on power calculations (described in [20]). The screening, which was done

[1]The terminology in the field is inconsistent. PA change/maintenance has been presented via *patterns* [2, 3], *trajectories* (especially in studies using trajectory modelling [4–6], but also in studies using other methods [7, 8]), *profiles* [6], *groups* [2, 9], *subgroups* [10], and *clusters* [2], all referring to the same population distributions on the basis of their PA change or maintenance over time.

in one of the six national Sports and Exercise Medicine Centres of Excellence, included screening by a physician, and a fasting blood sample [20]. Instruction was also given on the use of a hip-worn accelerometer, including guidance on wearing the device during waking hours for seven consecutive days, except during shower or water activities. Two-thirds (65%) of those participating in the baseline pre-participation screening at age 15 ($n = 590$) participated also in the follow-up screening at age 19 ($n = 371$). After excluding swimmers (as they were unable to use the accelerometer during their swimming training), 254 adolescents provided valid accelerometer data and written consent for both measurement points.

Measures

The PA and sedentary time of the study participants were measured via a Hookie accelerometer (AM20 Activity Meter, Hookie Technologies Ltd., Helsinki, Finland), which has been shown to be a valid measurement tool among both young persons [21] and adults [22, 23]. The accelerometer collected and stored tri-axial data as actual g-units with a 100 Hz sampling frequency. The data were analysed in units of 6 s' duration. The PA analysis was based on mean amplitude deviation analyses (MAD), calculated from a resultant tri-axial raw acceleration signal, and converted to metabolic equivalents (METs) [22, 23]. The accuracy of the energy consumption estimation for the MAD method is about 1.2 MET for bipedal locomotion over a wide range of speed. Light PA was defined as an MET value higher than or equal to 1.5, and less than 3.0 (with an MAD value of 22.5–91.5 mg), moderate PA as an MET value higher than or equal to 3.0 and less than 6.0 (91.5 mg–414 mg), and vigorous PA as an MET value higher than or equal to 3.0 (MAD over 414 mg) [23]. In further analyses, the values for moderate and vigorous activity were combined to form an MVPA group. Further details of the device measurements are presented in Additional file 2.

In line with the definition of sedentary behaviour [24], separate analyses were conducted on activity without movement under 1.5 MET while (i) seated or in a reclining/lying posture, and (ii) while standing. Determination of the body posture was based on two facts, namely that the earth's gravity vector is constant and that the body posture during walking is upright. The accelerometer orientation (in terms of the gravity vector during walking) was taken as the reference, and the angle for posture estimation (APE) was determined from the incident accelerometer orientation in relation to the reference vector [21]. If the total accelerometer wear-time exceeded 18 h per day, hours in excess of 18 were decreased from the sedentary time, as this indicated that the individual was wearing the device during sleep (1.3% of the measurement days).

The PA and sedentary time variables are reported as proportions of valid accelerometer wear-time, and MVPA as mean daily hours and minutes. In addition, we formulated a variable denoting *change in percentage of sedentary time* between baseline and follow-up measurements (based on the difference between baseline and follow-up in the percentage of device wear-time in sedentary positions, denoting either increasing or decreasing sedentary time).

Participation in SC was confirmed by questions in three separate surveys (e.g. 'Are you participating in SC activities?' with response options 'Yes' and 'No', and 'How many times during a normal week do you participate in coach-led training?') together with a training diary. Based on the categorization of SC participants and non-participants at baseline and follow-up, the *change in SC participation* was formed via a variable comprising four groups: (i) *never participated in SC*; (ii) *dropped out of SC*; (iii) *adopted SC participation*; and (iv) *maintained SC participation*. Because of the small number of cases in (iii) *adopted SC participation* ($n = 2$), categories (iii) and (iv) were combined into a single category, i.e. *maintained or adopted SC participation.*

AC to school (since the subjects were 15-year-olds) was estimated via the question 'How do you commute on your way to and from school at this time of year (select the single most common option)'. The corresponding question among 19-year-olds was assessment of AC to work or to study facilities. Commuters were categorized as 'active' (walking and cycling) or 'non-active' (those who selected any other response option, such as 'by car'). Based on this categorization at baseline and at follow-up, a variable denoting *change in AC* was formulated: (i) *never commuted actively*; (ii)) *stopped AC*; (iii) *adopted AC*; and (iv) *maintained AC*. Due to the small number of cases in (iii) *adopted AC* ($n = 27$), categories (iii) and (iv) were combined in the analysis within a single category, i.e. *maintained or adopted AC.*

Amount of school physical education (at age 15) was estimated via the question 'How many minutes of school physical education do you have in a week? (calculate class physical education plus any optional physical education you do at school)'.

Statistical analysis

To form different PA change and stability groups (encompassing PA patterns), an analysis was performed using a k-means algorithm for longitudinal data (KmL) [25]. The method grouped observations of physical activity (MVPA) at the two measurement points (ages 15 and 19) into homogeneous subgroups (i.e. clusters that were as heterogeneous as possible from each other). KmL has been shown to have good clustering performance, especially when the sample size or number of measurement points is small [26].

The KmL assigns each observation to a cluster, and the optimal solution is reached by altering two phases: (i) determining the centre of each cluster, and (ii) assigning each observation to its nearest cluster [25]. To find the optimal number of clusters and the best solution we allowed the KmL to run for two to six clusters, 20 times each. The final solution was decided according to the following criteria: (i) Calinski & Harabatz criterion (the optimal number of clusters is the number that maximizes the between-matrix variance and minimizes the within-matrix variance) [25]. As the solutions for four and five clusters were almost equally good, the decision was also based on (ii) the number of participants in each cluster (≥20 observations), and (iii) the amount of MVPA in the most inactive group (taken to be clearly under one hour per day at baseline). This made it possible to obtain meaningful comparisons between groups (bearing in mind that the recommendation for health-enhancing PA for children and adolescents is an average of (at least) 60 min/day of MVPA [27]). It is further in line with the common practice of validating cluster selection also by expert opinion (i.e. reasoning from the subject details) [25, 28].

The differences in frequencies between PA patterns were based on the Chi-square test and on Fisher's exact test. The Kruskal-Wallis test was used to analyse differences in mean values cross-sectionally (with post hoc Dunn's test, adjusted by the Bonferroni correction for multiple tests). The significance of the change over time was calculated by the McNemar test and the Wilcoxon signed rank test.

Multivariable binary logistic regression analysis was used to calculate odds ratios (ORs) and 95% confidence intervals (CIs) for the association between the explanatory variables (i) gender, changes in (ii) SC participation, (iii) active commuting, and (iv) percentage of device wear-time by sedentary time, and by membership of each PA group as compared to all the other patterns taken together (representing the outcome). The categories of *activity maintainers* and *increasers* were combined due to the relatively small number of *increasers* ($n = 20$), and because both of the categories represented a favourable evolution of PA in terms of health. The models were adjusted according to *the change in the device wear-time* to eliminate the effect of differences in usage time on the results.

Additional logistic regression analysis was conducted with self-rated health and sociodemographic factors as explanatory variables. Furthermore, linear regression analysis was carried out to illustrate the correlates and determinants for the PA change in the entire sample. In addition to the change in device wear-time and in the season applied in the first measurement, the linear regression analysis was adjusted for baseline MVPA (because the aim was to examine whether explanatory variables could be detected independently of baseline PA levels).

Data analysis was performed using SPSS version 24, except when identifying PA patterns with R package KmL (R software version 3.6.0). The significance level was $p < 0.05$ in all the statistical tests.

Results

Characteristics of the study sample

The study sample was 60% female (Table 1), and at baseline 65% of the participants lived in families with high affluence [see Additional file 3]. At post-measurement (age 19) most of the participants (69%) were still living with their parents. Half of the sample (49%) were studying in upper secondary education, while 15% of the participants were studying in higher education, and 21% had started work at post-measurement.

There were no differences in baseline MVPA, perceived health, family affluence, or self-reported PA between the study participants and those lost to follow-up [see Additional file 4]. Males and those who reported lower school achievement ($p < .001$), were more likely not to participate in the post-measurement.

Patterns of PA

Five distinct PA change patterns were identified (Fig. 1), concurrently with an overall decline in participants' ($n = 254$) mean MVPA (Table 1). The most prevalent patterns were *inactivity maintainers* ($n = 71$) and *activity maintainers* ($n = 70$). Two distinct declining PA patterns were found: *decreasers from moderate* (to low) *PA* ($n = 61$), and *decreasers from high* (to moderate) *PA* ($n = 32$). The analysis also revealed a small group of *increasers* ($n = 20$), whose mean daily MVPA was already at a high level at age 15 (1 h 50 min) (Table 1).

Distribution of different intensities of PA and sedentary behaviour among the PA patterns

Figure 2 illustrates the distribution of different intensities of PA among the PA change patterns. *Inactivity maintainers* spent a higher proportion of their waking hours in sedentary behaviour at age 15 (63.5%) as compared to the other PA patterns (51.6–57.8%), and at age 19 (60.7%), as compared to (at age 19) *activity maintainers* (53.4%) and *increasers* (45.0%) (Fig. 2). Standing still encompassed 10–13% of waking hours among all the patterns, and no changes over time were observed.

The time spent in light PA increased over time among *inactivity and activity maintainers*, and also among *increasers* (Fig. 2). Hence, total PA slightly increased among *inactivity maintainers* ($p = .009$), even if the corresponding proportion of MVPA decreased at the same

Table 1 MVPA and changes in self-reported domains of PA by PA patterns

		Total	PA patterns					p^a
			A	B	C	D	E	
N (%)		254 (100)	71 (28)	70 (28)	61 (24)	32 (13)	20 (8)	
Males, *n* (%)		101 (40)	19 (27)	25 (36)	22 (36)	26 (81)	9 (45)	**< 0.001**
MVPA mean per day: hours and minutes (SD)								
age 15		1:22 (0:33)	0:47 (0:12)	1:19 (0:17)	1:25 (0:12)	2:20 (0:24)	1:50 (0:28)	**A < B-E < 0.001** **B < D < 0.001** **B < E 0.004** **C < D < 0.001**
age 19		1:05[b] (0:34)	0:39 (0:15)	1:25 (0:15)	0:44 (0:11)	1:07 (0:21)	2:25 (0:31)	**A < B,D,E < 0.001** **B > C < 0.001** **B < D 0.037** **B < E < 0.001** **C < D,E < 0.001** **D < E < 0.001**
Sports club participation								
age 15, *n* (%)		176 (69)	29 (41)	51 (73)	47 (77)	31 (97)	18 (90)	**< 0.001**
age 19, *n* (%)		97 (38)	9 (13)	33 (47)	23 (38)	19 (59)	13 (65)	**< 0.001**
p for sig. Over time		**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	0.062	
change[a] *n* (%)	**never**	76 (30)	41 (58)	18 (26)	14 (23)	1 (3)	2 (10)	**< 0.001**
	dropout	81 (32)	21 (30)	19 (27)	24 (39)	12 (38)	5 (25)	0.499
	maintenance	95 (37)	8 (11)	32 (46)	23 (38)	19 (59)	13 (65)	**< 0.001**
	adopt	2 (1)	1 (1)	1 (1)	0 (0)	0 (0)	0 (0)	–
Active commuting								
age 15, *n* (%)		142 (57)	32 (47)	40 (58)	35 (57)	20 (67)	15 (75)	0.161
age 19, *n* (%)		76 (30)	17 (24)	25 (36)	20 (33)	6 (19)	8 (42)	0.228
p for sig. Over time		**< 0.001**	**0.009**	**0.009**	**0.012**	**0.008**	**0.039**	
change[a] *n* (%)	**never**	78 (32)	30 (49)	22 (36)	18 (34)	5 (20)	3 (17)	**0.036**
	dropout	94 (38)	21 (31)	22 (32)	23 (38)	19 (63)	9 (47)	**0.024**
	maintenance	47 (19)	10 (16)	18 (29)	12 (23)	1 (4)	6 (33)	**0.042**
	adopt	27 (11)	6 (9)	7 (10)	8 (13)	5 (17)	1 (5)	0.732
School physical education at age 15, mean minutes (*n*)		135 (239)	108 (66)	144 (66)	143 (59)	139 (28)	170 (20)	**A < B 0.022** **A < C 0.017** **A < E 0.001**

A = Inactivity maintainers, B = Activity maintainers, C = Decreasers from moderate PA, D = Decreasers from high PA, E = Increasers, MVPA = moderate-to-vigorous physical activity, PA = physical activity

[a] *p*-values have been calculated comparing the frequency of the individual response category to each of the corresponding response categories for the other PA patterns (e.g. dropout vs. no dropout (= never+maintenance+adopt))

[b] Significance over time $p < 0.001$. At age 15: 1 h 22 min = 9.7% of device wear-time; at age 19: 1 h 5 min = 7.9% of device wear-time

Note: *p*-values have been assessed using the Chi-square test or Fisher exact test (in cases of sparse data) for categorical variables. The Kruskal-Wallis test was used in analysing differences in mean values between PA patterns cross-sectionally (post hoc Dunn's test adjusted by the Bonferroni correction for multiple tests); the McNemar test and the Wilcoxon Signed Rank test were used to analyse differences over time

time. However, the proportion of total PA among *inactivity maintainers* at age 19 (28%) remained lower as compared to *activity maintainers* (35%), *decreasers from high PA* (33%), and *increasers* (45%).

Domains of PA by PA patterns

At age 15, SC participation and AC were prevalent in all the patterns (Table 1). Only SC participation differed by pattern ($p < .001$), varying from 41% of *inactivity maintainers* to 97% of *decreasers from high PA* at age 15. On average 57% of participants commuted actively to school.

SC participation and AC decreased over time among all the patterns, with the exception of SC participation among *increasers* ($p < .062$) (Table 1). The prevalence of dropout from SC did not vary with the pattern ($p = .499$, mean 32%). Withdrawal from AC was lowest (at 31%) among *activity maintainers*, and highest (at 63%) among *decreasers from high PA* ($p = .024$).

Inactivity maintainers reported less school physical education per week (mean 108 min), as compared to *activity maintainers* (144 min), *decreasers from moderate PA* (143 min), and *increasers* (170 min) (Table 1).

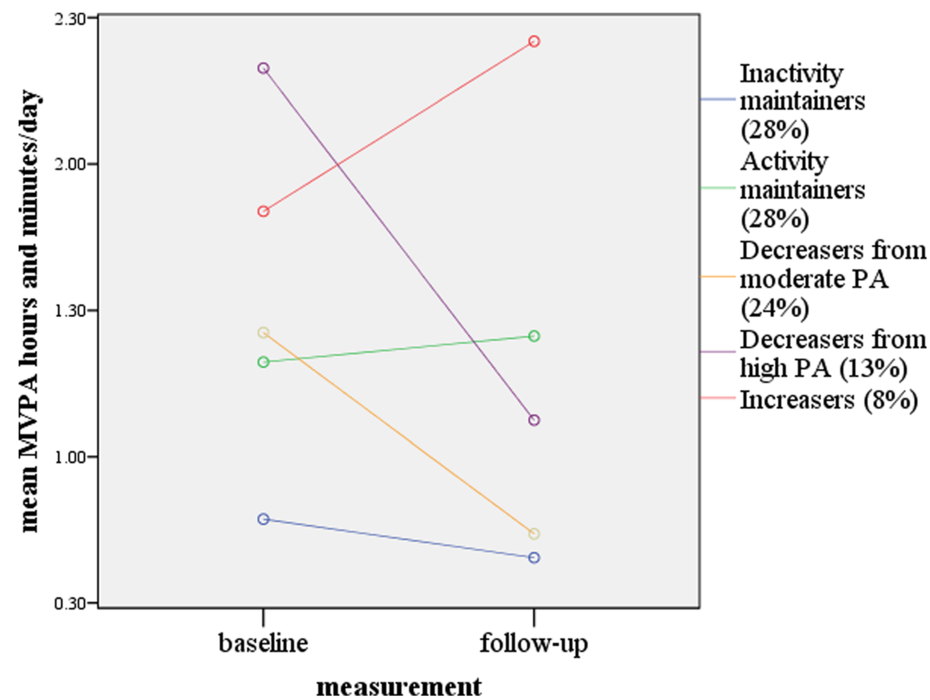

Fig. 1 Measured PA patterns (formed by the KmL data-driven clustering method [23]) (*n* = 254)

Simultaneous associations of changes in SC participation, AC, and sedentary time with PA patterns

Dropping out of SC (OR = 0.3, CI = 0.2–0.6) and maintained/adopted SC participation (OR = 0.1, CI = 0.02–0.2) – as opposed to 'never' participation in SC – were associated with lower odds of belonging to *inactivity maintainers* as compared to the other PA patterns (Table 2). Correspondingly, *maintained/adopted SC participation* – as opposed to 'never' participation in SC (OR = 3.6, CI = 1.8–7.4) – was associated with higher odds of belonging to the combined

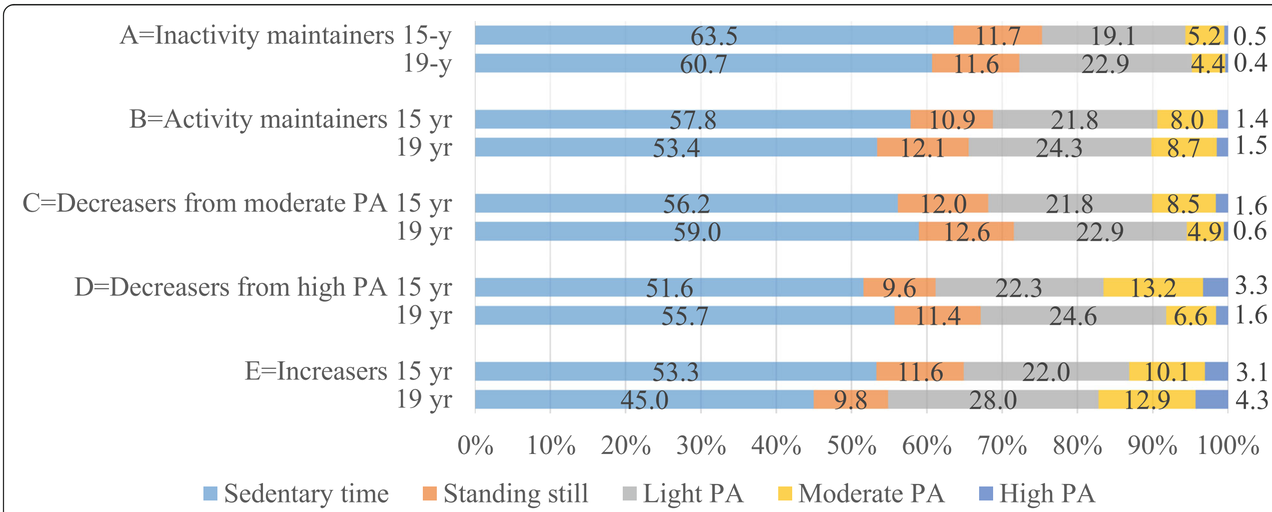

Fig. 2 Sedentary behaviour and physical activity (PA) as proportions of device wear-time by PA pattern. Sedentary time 15-y.: A > B**, C-E***, D < B**; 19-y.: E < D*, C, A***, B < C**, A***, change over time: B***, C**, D, E*. Standing still 15-y.: D < C*. Light PA 15-y.: A < B, D*, C**; change over time: A***, B**, E*. Moderate PA 15-y: A < B-E***, D > B, C***; 19-y.: A < B, D, E***, C < D*, C < B, E***, D < B**, E***; change over time: A, E*, C, D***. High PA 15-y: A < B-***, B < E**, D***, C < D**; 19-y.: A < B-E***, C < B, E***, D**; change over time: A*, C, D***. *p*-values determined from the Kruskal-Wallis test for differences in mean values between PA patterns cross-sectionally (post hoc Dunn's test adjusted by the Bonferroni correction for multiple tests) (only significant differences presented) and the significance of the changes over time in mean values by the Wilcoxon Signed rank test. **p* < 0.05, ***p* < 0.01, ****p* < 0.001

Table 2 Logistic regression models for physical activity patterns

	Inactivity maintainers		Activity maintainers + increasers		Decreasers from moderate PA		Decreasers from high PA	
	OR (95% CI)	*p*	OR (95% CI)	*p*	OR (95% CI)	*p*	OR (95% CI)	*p*
Gender								
Female	1.0		1.0		1.0		1.0	
Male	0.5 (0.2–1.01)	0.055	0.8 (0.4–1.4)	0.376	0.8 (0.4–1.5)	0.400	**7.4 (2.6–21.3)**	**< 0.001**
Sports club participation								
Maintenance or adopt	**0.1 (0.02–0.2)**	**< 0.001**	**3.6 (1.8–7.4)**	**< 0.001**	1.5 (0.7–3.3)	0.339	**11.2 (1.4–90.0)**	**0.023**
Withdrawal	**0.3 (0.2–0.6)**	**0.001**	1.2 (0.6–2.5)	0.625	1.9 (0.9–4.3)	0.097	**10.9 (1.3–90.7)**	**0.027**
Never	1.0		1.0		1.0		1.0	
Active commuting								
Maintenance or adopt	**0.3 (0.1–0.7)**	**0.004**	1.7 (0.8–3.4)	0.165	1.5 (0.7–3.2)	0.343	1.3 (0.3–4.7)	0.744
Withdrawal	0.5 (0.2–1.03)	0.061	1.0 (0.5–2.0)	0.989	1.2 (0.5–2.5)	0.708	2.3 (0.8–7.3)	0.144
Never	1.0		1.0		1.0		1.0	
Change in % of device wear-time by sedentary time	0.99 (0.96–1.02)	0.359	**0.96 (.93–.98)**	**0.001**	**1.05 (1.01–1.07)**	**0.004**	**1.04 (1.001–1.083)**	**0.046**
Model statistics:								
R^2 Nagelkerke	0.324		0.179		0.113		0.347	
R^2 Cox&Snell	0.223		0.131		0.076		0.182	
Hosmer&Lemeshow	0.148		0.631		0.241		0.998	

Note: Adjusted for change in the device wear-time. Statistically significant odds ratios are in bold. Binary analysis: separately for each pattern vs. all the others together. PA = physical activity

group of *activity maintainers and increasers*, as compared to the other PA patterns. Moreover, dropping out of SC (OR = 10.9, CI = 1.3–90.7) and maintenance/adoption of SC participation (OR = 11.2, CI = 1.4–90.0) – as opposed to 'never' participation in SC – were significant predictors for belonging to *decreasers from high PA*.

Decreased sedentary time (OR = 0.96, CI = 0.93–0.98) was associated with higher odds of being in the combined group of *activity maintainers and increasers* as compared to other PA patterns (Table 2). Correspondingly, an increased sedentary time was related to higher odds of being a *decreaser from moderate PA* (OR = 1.05, CI = 1.01–1.07) and *decreaser from high PA* (OR = 1.04, CI = 1.0–1.1).

Male gender was associated with increased odds of being a *decreaser from high PA* (OR = 7.4, CI = 2.6–21.3) (Table 2). Maintained/adopted AC (OR = 0.3, CI = 0.1–0.7) – as opposed to 'never' (at either at age 15 or age 19) participation in active commuting – was associated with lower odds of being an *inactivity maintainer.*

Sociodemographic characteristics and self-rated health among PA patterns

The analysis in Additional file 3 shows that no differences were observed between PA change patterns in any of the studied sociodemographic variables. However, good self-rated health related to higher odds of belonging to the combined group of *activity maintainers and increasers*, (OR = 2.7, CI = 1.1–6.8) and lower odds of being an *inactivity maintainer* (OR = 0.4, CI = 0.2–0.9) [see Table 3 and 1 in Additional file 5].

Discussion

Despite a general declining tendency in mean MVPA (see also [1]), the evolution of PA from adolescence to young adulthood varied greatly. The PA analysis identified five distinct PA patterns. Half of the study population maintained their activity or inactivity, while two groups with declining PA were observed, starting from a different baseline MVPA level (high or moderate). There was also a small group of increasers, who were already highly active at baseline (age 15). Furthermore, the changes in SC participation, AC, and sedentary time showed different relationships with the PA patterns. The results support the use of tailored PA promotion for the different subgroups.

Previous studies identifying longitudinal PA patterns during adolescence [2–4, 7, 11] have varied in the amount and prevalence of patterns, the characteristics of the study sample (e.g. size and number of measurement points), methods for PA measurement, and cluster identification. Any subgroup of increasers detected has been small, with a prevalence varying between 7 and 12% [2, 3, 7]. This is consistent with the findings of the present study.

Inactivity maintainers turned out to be a group in which *all* the examined PA domains were less likely to occur. In this group, inactivity appeared in many forms: in a lower level of school physical education – indicating a lower selection of optional physical education classes – and a higher risk of non-participation in SC and AC as compared to the other PA groups. Promotion of any of the studied PA domains might have potential for increasing total PA. However, PA is a complex behaviour, and an increase in one PA domain might result in a decrease in another domain.

An important finding was that AC prevalence declined in all the groups (with dropout prevalence varying from 31 to 63%), even if the AC change significantly differentiated only the *inactivity maintainers* from the rest of the study population. Previous studies have found either a declining or a stable AC trend among young people on average [17]. Interestingly, AC maintenance during adolescence has been found to predict later midlife PA [29]. There seems good reason to encourage young people to maintain or adopt active forms of transport – including in post-school years – at least when the distances involved make AC feasible.

It is notable that as many as 41% of the *inactivity maintainers* were participating in SC at age 15. The result implies that SC participation does not guarantee sufficient PA for all adolescents, in terms of the recommendations for health-enhancing PA (i.e. at least one hour per day on average) [27]. Corresponding results have previously been found in a sample of SC participants [30]. However, one should take into account that the population in the present study represents young people who are more active than the average in Finland; in fact the mean daily MVPA was eight minutes more than that found in a population-based study [31]. Moreover, the *inactivity maintainers* in the present study were relatively active (mean daily MVPA = 47 min at age 15). In some previous studies, participants in the 'consistently inactive' trajectory have been clearly less active, with a mean daily MVPA of less than 30 min at age 15 [2, 10, 12, 13, 32]. One of those studies also explored participation in sports, and *all* of the subjects in the most inactive pattern also followed a trajectory of no participation in sports [13].

Despite the above, the message of this study is clear. SC participation was associated with a sustained or increased PA pattern, and correspondingly, SC withdrawal with a PA decrease from a high level. The relationship between sports participation at adolescence and PA in later life has been noted in previous studies [3, 33]. Although SC participation showed a range of associations with PA patterns, dropout from SC was common in all the patterns (mean 32%). In terms of PA promotion, the challenges are two-fold: how to prevent dropout from SC, and how to support compensatory PA as a substitute for SC activities, in cases where SC participation has come to an end during young adulthood.

Male participants were more likely to be present in the group exhibiting declining PA from a high baseline level. A review of previous studies found a slightly larger decrease in males than in females from adolescence to adulthood, possibly due to higher activity levels in youth [1]. The present study also indicated that even if PA declined from high PA levels, most of the young people in this group were still physically active, since they actually fulfilled the PA guidelines for children and adolescents at age 19 [27].

Decreasers from moderate PA formed the only group in which, at age 19, the activity fell to approximately the same level as that of the *inactivity maintainers*. Furthermore, as compared to the other patterns, the pattern of PA decrease from a moderate to a low level was not predicted by gender, or by sociodemographic factors; nor was it related to certain types of changes in SC participation or AC. Withdrawal from AC and SC between ages 15 and 19 was common overall. It amounted to over one third among *decreasers from moderate PA*, but as the development was *on average* the same in the rest of the study population, no difference was found relative to the other patterns. Future research will be needed to examine other possible determinants and correlates that could characterize this pattern of declining activity. Moreover, more research in general is called for regarding longitudinal PA patterns and their determinants [10, 12, 14]; these might include social and environmental factors, health behaviour, and life changes [11]. If the aim in future is to achieve a deeper understanding of the changes in PA domains over time, various up-to-date methods will be applicable, including GPS [34].

This study indicated that changes in MVPA reflected changes in sedentary behaviour, with increased sedentary time being more likely to occur within the declining PA patterns. Although the result seems somewhat self-evident, it emphasizes the importance of seeking possibilities to discourage sedentary behaviour, as a means to prevent PA decrease. However, among the *inactivity maintainers*, light PA increased at the same time as MVPA slightly decreased – though without any changes in sedentary time. On this basis, one cannot actually claim that sedentary time and MVPA directly displace one another (see also [19]).

Interestingly none of the studied sociodemographic variables related to PA change patterns. The patterns did not even differ in terms of family affluence, despite findings in some previous studies indicating that family socioeconomic factors could explain differences between PA change patterns [3, 16]. Many typical life changes had not occurred at age 19, given that most of the participants were still living with their parents. Only a minority had started studying in higher education or embarked on working life. Hence, in future studies, possible differences in life events and choices between distinct PA change patterns should be examined. Furthermore, differences in the health and health behaviour of young adults in terms of PA patterns will be an important research topic in future, bearing in mind that the results of self-reported health differentiated between PA patterns.

The following limitations should be noted: the study sample was relatively small and does not represent the entire Finnish population of the age cohort in question, even though it was collected from different parts of Finland. Participation in terms of gender and school achievement was unequal. Rather more winter measurements were conducted during the first data collection period as compared to the second data collection; however, difference was taken into account in the analysis. Moreover, partly because of the sampling method (involving both sports clubs and schools), the young people represented by the data are more active than on average; however, this could also be regarded as a strength, insofar as the data enable thorough analysis of high PA maintenance and SC participation. One should also note that additional PA measurement periods would have strengthened the validity of the results, with possibilities for different PA change patterns to be identified between the baseline and post-measurement.

The main strength of the present study is the provision of longitudinal, objectively measured PA data from the (less often studied) period from adolescence to young adulthood (see also [1, 11, 35]), over a diverse sample of Finnish young people. The data-driven extraction of longitudinal PA patterns (KmL) [25] represents a modern way to research change and stability in PA behaviour over time. It should be noted that a linear regression analysis for the entire sample is unable to illustrate the differences in determinants and correlates between distinct PA change patterns [see Additional file 6]. This highlights the importance of pattern-based analysis. Another novel aspect is the analysis of multiple PA domains in relation to PA patterns, taking into account the change in both outcome (PA patterns) and explanatory variables. Former prospective studies on changes in PA domains have rarely included several domains in the same sample [17].

Conclusions

Five distinct PA change and stability patterns could be identified. Dropout from SC and from AC was prevalent in all the PA patterns. The study highlights the importance of SC participation in supporting maintenance of PA, and preventing a decrease in PA. An absence of AC and of SC participation was associated with sustained inactivity from adolescence to young adulthood. The group of inactivity maintainers also reported a lower level of (optional) school physical education as compared to the other PA patterns. In tackling sustained inactivity in the youth population, actions that increase any of the studied PA domains may be appropriate. Preventing dropout from organized sports, and supporting substitutes for SC participation, may be appropriate for preventing a decrease in PA. Similarly, to sustain sufficient activity, young people who up to now have followed favourable PA patterns may benefit from further supportive actions. However, these assumptions need to be tested in intervention studies tailored towards particular PA change and stability patterns. The influence of psychosocial and environmental factors in explaining differences between PA change patterns remains to be investigated in future research.

Abbreviations

AC: active commuting; CI: confidence interval; MVPA: moderate-to-vigorous physical activity; OR: odds ratio; PA: physical activity; SC: sports club

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12966-021-01130-x.

Additional file 1. Flow of participants in this study: persons who participated in pre-participation screening for the Health Promoting Sports Club (HPSC) study and who had valid accelerometer data from both measurement points.

Additional file 2. Device-measurement periods by PA change patterns.

Additional file 3. Sociodemographic characteristics and self-rated health of the participants, by PA change patterns [36–38].

Additional file 4. The loss to the follow-up analysis [36, 37].

Additional file 5. Associations of sociodemographic factors and measurement season with physical activity change patterns via logistic regression analysis.

Additional file 6. Associations between background variables and change in moderate-to-vigorous physical activity from age 15 to 19.

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Authors' contributions

SK is the principal investigator for the HPSC study, and was a major contributor in reviewing the manuscript together with TV. TA designed and conducted most of the analyses and drafted the manuscript, HV was responsible for processing the accelerometer data, JV conducted the KmL analysis, and JK and JV advised on the statistical aspects of the study. TV, OH, RK, JK, JP, KS, AU, MV, HV, and SK critically reviewed the final manuscript. All the authors contributed to the design of the work, and read and approved the final manuscript.

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Availability of data and materials
The datasets generated and/or analysed during the current study are not publicly available, since they contain confidential personal details and health information but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
The HPSC study was conducted in accordance with the Declaration of Helsinki, and received ethical approval from the Ethics Committee of the Healthcare District of Central Finland (20.12.2012 (23 U/2012), 15.12.2016). Written consent was required from the participants, and also from a guardian when the participant was aged under 18. The permission notification included detailed information on the study, plus notification on the right of participants to refuse, and to withdraw their consent without giving a reason.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

Author details
[1]Faculty of Sport and Health Sciences, Research Centre for Health Promotion, University of Jyväskylä, PL 35, FI-40014 Jyväskylä, Finland. [2]UKK Institute of Health Promotion Research, Kaupinpuistonkatu 1, FI-33500 Tampere, Finland. [3]Faculty of Medicine and Health Technology, Tampere University, Tampere, Finland. [4]Paavo Nurmi Centre & Unit for Health and Physical Activity, University of Turku, Kiinamyllykatu 10, FI-20520 Turku, Finland. [5]Medical Research Center (MRC), University of Oulu and University Hospital of Oulu, Oulu, Finland. [6]Department of Sports and Exercise Medicine, Oulu Deaconess Institute Foundation sr, P.O. Box 365, FI-90101 Oulu, Finland. [7]Center for Life Course Health Research, University of Oulu, Oulu, Finland. [8]Department of Mathematics and Statistics, University of Jyväskylä, P.O. Box 35, Jyväskylä, Finland. [9]Tampere Research Center of Sports Medicine, Kaupinpuistonkatu 1, FI-33500 Tampere, Finland. [10]Department of Clinical Physiology and Nuclear Medicine, Kuopio University Hospital, Kuopio, Finland. [11]Kuopio Research Institute of Exercise Medicine, Haapaniementie 16, FI-70100 Kuopio, Finland. [12]Clinic for Sports and Exercise Medicine, Foundation for Sports and Exercise Medicine, Alppikatu 2, FI-00530 Helsinki, Finland. [13]Department of Sports and Exercise Medicine, Clinicum, University of Helsinki, Helsinki, Finland. [14]Research Center for Olympic Sports, Rautpohjankatu 6, FI-40700 Jyväskylä, Finland.

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II

PSYCHOSOCIAL AND HEALTH BEHAVIOURAL CHARACTERISTICS OF LONGITUDINAL PHYSICAL ACTIVITY PATTERNS: A COHORT STUDY FROM ADOLESCENCE TO YOUNG ADULTHOOD

by

Aira, T., Vasankari, T., Heinonen, O. J., Korpelainen, R., Kotkajuuri, J., Parkkari, J., Savonen, K., Toivo, K., Uusitalo, A., Valtonen, M., Villberg, J., Vähä-Ypyä, H., & Kokko, S. P. 2023

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RESEARCH

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Psychosocial and health behavioural characteristics of longitudinal physical activity patterns: a cohort study from adolescence to young adulthood

Tuula Aira[1*], Tommi Vasankari[2,3], Olli J Heinonen[4], Raija Korpelainen[5,6,7], Jimi Kotkajuuri[8], Jari Parkkari[9,10], Kai Savonen[11,12], Kerttu Toivo[9], Arja Uusitalo[13,14], Maarit Valtonen[15], Jari Villberg[1], Henri Vähä-Ypyä[2] and Sami P Kokko[1]

Abstract

Background The decline in physical activity (PA) during adolescence is well-established. However, while some subgroups of adolescents follow the general pattern of decreased activity, others increase or maintain high or low activity. The correlates and determinants of different PA patterns may vary, offering valuable information for targeted health promotion. This study aimed to examine how psychosocial factors, health behaviours, and PA domains are associated with longitudinal PA patterns from adolescence to young adulthood.

Methods This prospective study encompassed 254 participants measured at mean ages 15 and 19. Device-measured moderate-to-vigorous PA was grouped into five patterns (*activity maintainers, inactivity maintainers, decreasers from moderate to low PA, decreasers from high to moderate PA, increasers*) via a data-driven method, K-Means for longitudinal data. Multinomial logistic regression was used to analyse the associations between health behaviours, psychosocial factors, PA domains, and different PA patterns.

Results A lack of sports club participation characterised *inactivity maintainers* throughout adolescence. Difficulties in communicating with one's father at age 15 were associated with higher odds of belonging to *inactivity maintainers* and to *decreasers from moderate to low PA*. Lower fruit and vegetable consumption at age 19 was also related to increased odds of belonging to the groups of *inactivity maintainers* and *decreasers from moderate to low PA*. Smoking at age 19 was associated with being a *decreaser from moderate to low PA*.

Conclusions Diverse factors characterise longitudinal PA patterns over the transition to young adulthood. Sports club participation contributes to maintained PA. Moreover, a father-adolescent relationship that supports open communication may be one determinant for sustained PA during adolescence. A healthier diet and non-smoking as a young adult are associated with more favourable PA development.

Keywords Adolescent, Health Behaviour, Physical activity, Psychosocial factors, Young Adult

*Correspondence:
Tuula Aira
tuula.m.aira@jyu.fi

Full list of author information is available at the end of the article

Background

The decline in physical activity (PA) during adolescence is a global health concern [1]. Overall, PA tends to decline with increasing age [2, 3], such that as compared to younger age groups [1], more adolescents fail to meet the one-hour moderate-to-vigorous PA (MVPA) per day recommendation [4]. However, despite the overall decline in PA, considerable individual variation exists in the development of PA over adolescent years – a point illustrated by studies identifying distinct longitudinal PA patterns or trajectories [5–9]. There is a need for studies to determine how those adolescents who maintain favourable PA differ from those who decrease their activity, or those who maintain an inactive lifestyle. Such research would open up possibilities to guide PA interventions [2, 5, 6, 10].

PA is a complex behaviour, varying over time. Numerous theories and models have been applied to shed light on it. One of these, the (socio)ecological model, is based on the idea that PA may be influenced by (1) individual (e.g. genetic or psychological) factors, (2) social or cultural factors, (3) the built environment, and (4) policies [11, 12]. Thus, the determinants and correlates of longitudinal PA patterns may exist at many levels. Moreover, the contexts of living and of PA change over the life course [13–15], and this further increases the possible correlates for sustained and changed PA. The transition to young adulthood typically involves increasing autonomy. This is frequently linked to important changes (such as moving out of the childhood family home, or entering higher education or employment) that may predispose individuals to changing their health behaviours. As well as acknowledging the changes in environments and the impacts of life events during the lifespan, the life course approach considers the impact of earlier life phases on subsequent phases, and assumes that there may be ideal times for intervening in health behaviours [16–18].

A number of possible correlates/determinants for longitudinal PA patterns during adolescence have previously been examined, including maturity [7, 19, 20], socioeconomic status [21], other health behaviours [19, 20], support for PA [20, 21], PA domains [5], and distance to the nearest park and school [20]. However, the research base is still limited, and apart from family and peer support for PA, the psychosocial factors correlating with PA patterns have received little attention. Moreover, for the most part, only a single health behaviour has been studied in relation to longitudinal PA patterns [6, 20], even if there would be reason to examine the possible accumulation of behavioural risk and/or protective factors in relation to longitudinal PA patterns. Overall, information on the co-occurring and multidimensional characteristics of longitudinal PA patterns could be valuable for health promotion, one aim of which is to increase or maintain physical activity during adolescence.

Another limitation in previous research is that only some studies have used accelerometry in PA assessment rather than self-reported measurements; furthermore, the majority of studies have not applied data-driven methods for identifying distinct PA patterns. Data-driven methods can better identify genuinely heterogeneous PA patterns as compared to subjective methods (which can involve splitting into quartiles, or applying predetermined levels of PA).

Our aim was to study how psychosocial factors (*loneliness, weight satisfaction, ease in talking to parents, exercise with parents*) and health behaviours (*alcohol, tobacco, and snuff use, amount of sleep, eating behaviours, toothbrushing*) are associated with longitudinal PA patterns from adolescence to young adulthood (referring here to the patterns represented by *activity maintainers, inactivity maintainers, decreasers from moderate to low PA, decreasers from high to moderate PA*, and *increasers* [5]). Moreover, the associations between activity domains and PA patterns were examined together with psychosocial factors and health behaviour, the aim being to assess the most important correlates for sustained and changed PA during the transition to young adulthood. In previous analyses using the same study data, changes in sports club participation have emerged as significantly related to maintained and decreased PA, and passive commuting throughout adolescence has been found to be related to maintained inactivity [5]. Thus, we hypothesised that when analysed together with the other studied factors, we would find participation in a sports club to be related to maintained or increased PA, and passive commuting to maintained inactivity. Moreover, we hypothesised that (1) decreasing PA to a low level, and (2) maintained inactivity, would be associated with at least some health-compromising behaviours and psychosocial challenges.

Methods

Participants and study procedure

The data for this observational cohort study were drawn from the Health Promoting Sports Club study (HPSC), conducted in the years 2013–2014 and 2017–2018. At baseline, the participants (mean age 15) were recruited on the basis of power calculations [22] from 156 sports clubs and 100 schools within six large cities and surrounding communities in different parts of Finland [5, 20].

The procedure was the same at baseline and follow-up. Hence, the participants took part in electronic surveys on current health status and behaviours, and participated in medical examinations containing screening by a physician, a fasting blood sample, and instructions to use a hip-worn accelerometer (seven consecutive days during waking hours, except when bathing or doing water activities).

Nearly two thirds (64%) of the baseline participants (n=583, mean age 15.5, SD 0.6), also took part in follow-up measurements (n=371, mean age 19.4, SD 0.6). In total, 254 adolescents (60% females) provided valid accelerometry data for both measurements (swimmers excluded: n=22, at least four days, 10 h/day). See [5, 20] for more study details.

Measures

Outcomes (longitudinal PA patterns)

PA was measured via a Hookie accelerometer (AM20 Activity Meter, Hookie Technologies Ltd., Helsinki, Finland), which collected and stored tri-axial data as actual g-units (100 Hz sampling frequency). The data were analysed in units of 6 seconds' duration. The PA analysis was based on mean amplitude deviation analyses (MAD), calculated from a resultant tri-axial raw acceleration signal, and converted to metabolic equivalents (METs) [23, 24]. The epoch-wise MET values were further smoothed by calculating the 1-minute exponential moving average MET value for each epoch time point. MVPA was defined as ≥3.0 METs.

The formulation and details of the longitudinal PA patterns have been described previously [5]. In brief, by applying k-means for longitudinal data (KmL) [25] based on the two MVPA measurement periods, the participants were grouped into distinct clusters so that the clusters were as different from each other as possible. The KmL method belongs to classical algorithmic approaches (hierarchical or partitional clustering), but similar model-based methods also exist, such as mixture modelling techniques or latent class analysis [25]. In this study, the KmL was selected, as it could be run with only two measurement points. Moreover, it performs especially well when the sample size is small [26], and it is computationally less complex [27]. The longitudinal PA patterns (clusters) arrived at consisted of *inactivity maintainers, activity maintainers, decreasers from moderate (to low) PA, decreasers from high (to moderate) PA* (see Additional file 1).

Exposure variables

The potential correlates and determinants of interest were drawn from electronic surveys. With a few exceptions, the questions were based on the international Health Behaviour in School-aged Children (HBSC) study [1], and were repeated identically at both time points (unless otherwise stated). All the HBSC survey questions have been subject to validation and piloting at national and international levels [28], and many of the items have been assessed for their test-retest reliability [28, 29].

The questions assessing *sports club participation* and *active commuting* have been described elsewhere [5]. Dichotomous variables were used to assess participation in sports clubs and active commuting (by bike or on foot) to school (age 15), or to the study place or work (age 19). The questions assessing active commuting were modified from the *Finnish schools on the Move* survey [30].

Psychosocial variables: *Loneliness* was measured by one question: 'Do you ever feel lonely?' In further categorisation, the response options *very often* and *often* were combined, as were *sometimes* and *never*. A question estimating *satisfaction with one's own current weight* included two response options (*yes/no*), and it was created for the purposes of the present study.

Communication with parents: The study participants were asked how easy it was for them to talk to their mother about things that really bothered them. The response options were: *very easy, easy, difficult*, and *very difficult*, with the additional response option *I don't have or see this person*. Identical questions were posed regarding communication with the father and (if applicable) stepfather and stepmother. Separate dichotomised variables (*easy* vs. *difficult*) were formed for communication with (1) the mother and (2) the father. The latter also included talking over difficulties with one's stepfather in cases where the respondent did not have a father (baseline n=3, follow-up n=5). Cases were excluded where there was neither mother nor stepmother (baseline n=3, follow-up n=8) (and similarly neither father nor stepfather, baseline n=14, follow-up n=16).

The frequency of *exercising together with a parent* was assessed via a question: 'During a typical week: How often does your mother (or your stepmother if your mother does not live in your primary home)…. exercise or do sport with you?' A corresponding question assessed exercising together with the father. Two categories were formed, encompassing (1) *sometimes* to *very often*, and (2) *never* to *occasionally*. Category 2 also included not having the parent in question, or not seeing that parent.

Health behaviour: The *frequency of alcohol consumption* was based on a question used in the Finnish School Health Promotion (SHP) study [31]: 'On the whole, how often do you consume alcohol, for example a half-bottle of beer or more?'. The response options ranged from *Once a week or more often* to *I don't drink alcoholic beverages*. A dichotomised variable was formed: (1) *at least once a month*, (2) *less frequently or no consumption at all.*

Lifetime drunkenness was based on a question asking adolescents whether they had ever had so much alcohol that they were really drunk. The response alternatives ranged from *never* to *more than 10 times*. A dichotomised variable was formed for lifetime drunkenness: (1) *two times or more* vs. (2) *never or once.*

Snuff use was assessed via the following question 'Do you currently use snuff?' The responses were categorised into two groups encompassing (1) *less frequently* to *every day*, (2) *non-users*. A correspondingly dichotomised variable was used to assess *smoking frequency*. Here, the categories *less than weekly, weekly*, and *daily smokers* were combined, due to the overall small proportion of current daily smokers at age 15.

Toothbrushing frequency was determined via a question: 'How often do you brush your teeth?'. The answer options were dichotomised (< *twice daily* vs. *twice daily*) according to the international recommendation of twice-daily toothbrushing. Furthermore, the responses on *frequency of eating breakfast on weekdays* and *frequency of eating school meals* were dichotomised to (*5 days* vs. *4 days or less per week*).

The *fruit and vegetable index* and the *sweets and sugared soft drinks index* were based on a question assessing the consumption of listed foods and drinks. The response options ranged from *never* to *every day, more than once*. The vegetable index ranged from *0* to *14*, where value 0 represented *no fruit and vegetable consumption*, and value 14 *consumption of both fruit and vegetables at least once a day*. Correspondingly, value 0 indicated *consuming both sweets and sugared soft drinks at least once a day*, while value 14 indicated *never eating sweets and sugared soft drinks* (for more details see 32, 33). Energy drinks (with examples given such as Battery, RedBull) were also among the listed foods and drinks, and adolescents' responses indicating *energy drink consumption* were categorised into two groups: (1) *at least weekly*, (2) *never or less than weekly*.

The amount of sleep was asked by a question created for the purposes of the present study: 'How many hours do you sleep on average on weekdays?'. Respondents reported the amount by a number.

Data analysis

The cross-sectional differences between PA patterns were assessed with cross-tabulations and Chi-square test/Fisher's exact test for categorial variables, and with the Kruskall-Wallis test (with post hoc Dunn's test, adjusted by the Bonferroni correction for multiple tests) for continuous variables.

Multinomial logistic regression analyses were conducted to calculate odds ratios (ORs) with 95% confidence intervals (CIs) for the associations between the exposure variables and membership of PA patterns. For these analyses, the categories of *activity maintainers* and *increasers* were combined due to the relatively small number of increasers (n=20), and because both categories represented a favourable evolution of PA in terms of health. This combined group was used as a reference in the analyses. Multiple different models were tested with the forced entry method, until the best-fitting ones were reached separately for (1) the baseline (mean age 15) and (2) the follow-up (mean age 19). Thus, the models (1) predicted membership of each pattern by determinants from the baseline (mean age 15), and (2) characterised the patterns at mean age 19 (longitudinal correlates). The models were adjusted for the *measurement interval* (age at the 2nd measurement minus age at the 1st measurement) and for the *change in device wear-time*. Missing cases (n=1–14) were excluded from the analyses. The data analysis was performed using SPSS version 26, and the significance level was set at $p<0.05$ in all the statistical tests.

Results

Descriptive information

Detailed descriptive information on the study participants has been provided previously [5], see also Additional file 2. Briefly, at baseline, nearly two-thirds (62%) of the participants lived in families with high affluence. At follow-up, most of the participants (69%) were still living with their parents. Half of the sample (49%) were studying in upper secondary education, while 13% were studying in higher education, and 21% were working (not studying) during the follow-up measurement. The *inactivity maintainers* were mostly females (73%), while the *decreasers from high to moderate* were mostly males (vs. 19% females). There were no other differences in sociodemographic characteristics between the PA patterns (see Additional file 2).

A previous study found no differences in baseline MVPA, family affluence, or perceived health between the baseline participants and those lost to follow-up [5]. However, males, and those who reported lower school achievement, were more likely not to participate in the post-measurement ($p<0.001$).

Psychosocial and health behavioural characteristics of the PA patterns: univariable analysis

As shown in Tables 1 and 2, there were differences between PA patterns in multiple psychosocial variables (loneliness, communication difficulties with father, exercise with parents, and weight satisfaction) and in some health behaviours (smoking, dietary habits, and sleep). For example, *exercising together with a parent at least occasionally* was less frequent among *inactivity maintainers* (57%) and *decreasers from moderate to low* (59%) at age 15 as compared to *increasers* (95%) (Table 1). Health behaviours did not differ between PA patterns at age 15, apart from a slightly lower average sleep amount among *inactivity maintainers* as compared to *decreasers from high to moderate PA* and *increasers* (Table 2).

Table 1 Psychosocial characteristics compared between longitudinal physical activity patterns, *n* (%)

	All	Inactivity maintainers	Activity maintainers	Decreasers from moderate PA	Decreasers from high PA	Increasers	*p*-value
Feeling loneliness quite often/often							
age 15	15 (6)	6 (9)	4 (6)	2 (3)	2 (7)	1 (5)	0.778
age 19	24 (10)	10 (14)	4 (6)	10 (16)	0	0	0.017
Ease of talking with mother							
age 15	202 (82)	57 (84)	57 (84)	44 (73)	26 (87)	18 (90)	0.390
age 19	208 (83)	57 (81)	54 (77)	49 (82)	30 (94)	18 (95)	0.182
Ease of talking with father							
age 15	163 (68)	38 (57)	49 (77)	33 (55)	26 (90)	17 (85)	< 0.001
age 19	153 (64)	41 (61)	37 (56)	34 (60)	24 (83)	17 (90)	0.012
Ease of talking with at least one parent							
age 15	209 (85)	58 (85)	61 (88)	46 (77)	26 (87)	18 (90)	0.434
age 19	217 (86)	60 (86)	56 (80)	52 (85)	30 (94)	19 (100)	0.139
Mother exercises or does sport with you at least occasionally							
age 15	106 (43)	27 (40)	35 (51)	20 (33)	10 (33)	14 (70)	0.020
age 19	88 (35)	18 (26)	30 (43)	22 (36)	5 (16)	13 (68)	0.001
Father exercises or does sport with you at least occasionally							
age 15	120 (48)	21 (31)	38 (55)	25 (41)	17 (57)	19 (95)	< 0.001
age 19	73 (29)	16 (23)	24 (35)	15 (25)	7 (23)	11 (58)	0.024
At least one parent exercises or does sport with you							
age 15	162 (65)	39 (57)	49 (71)	36 (59)	19 (63)	19 (95)	0.010
age 19	119 (47)	30 (43)	40 (57)	29 (48)	7 (23)	13 (68)	0.006
Satisfied with one's own weight							
age 15	194 (77)	46 (67)	51 (74)	47 (77)	31 (97)	19 (95)	0.002
age 19	179 (72)	41 (59)	51 (73)	40 (69)	30 (94)	17 (85)	0.003

Note: The identification of the longitudinal physical activity patterns was based on two valid accelerometry measurement periods of moderate-to-vigorous physical activity, and used a data-driven method (K-means for longitudinal data, KmL [25]) [5]. *p*-values have been assessed using the Chi-square test or Fisher's exact test (in cases of sparse data) for categorical variables

Correlates and determinants (multivariable analysis)

The most significant correlates and determinants for belonging to PA patterns were detected via multinomial logistic regression, using the combined group of *activity maintainers* and *increasers* as a reference (Figs. 1 and 2, Additional file 3). Both of the best-fitting models included *sports club participation* and *gender* as the most significant exposure variables, together with *talking about difficulties with one's father* (using a model consisting of only baseline predictors) and *fruit and vegetable consumption* (using a model consisting of only exposure variables from follow-up measurements).

Not participating in a sports club (OR: 4.6; CI: 2.2–9.6) and *communication difficulties with one's father* (OR: 2.4; CI: 1.1–5.1) at age 15 were associated with increased odds of being an *inactivity maintainer* as compared to membership of a group with favourable PA development. Correspondingly, *communication difficulties with one's father* at age 15 (OR: 3.3; CI: 1.6–7.1) was related to belonging to *decreasers from moderate to low PA*. *Male gender* was the only significant determinant for belonging to the *decreasers from high PA*.

Female gender (OR: 2.4; CI: 1.03–5.4), *lower fruit and vegetable consumption* (OR: 0.8; CI: 0.7–0.9), and *not participating in a sports club at age 19* (OR: 6.4; CI: 2.6–14.7) were associated with increased odds of being an *inactivity maintainer* as compared to belonging to the combined group of *activity maintainers* and *increasers. A lower fruit and vegetable consumption index at age 19* (OR: 0.9; CI: 0.8–0.97) was also related to being a *decreaser from moderate PA*. The same was true of *smoking* (OR: 3.0; 1.005–8.8).

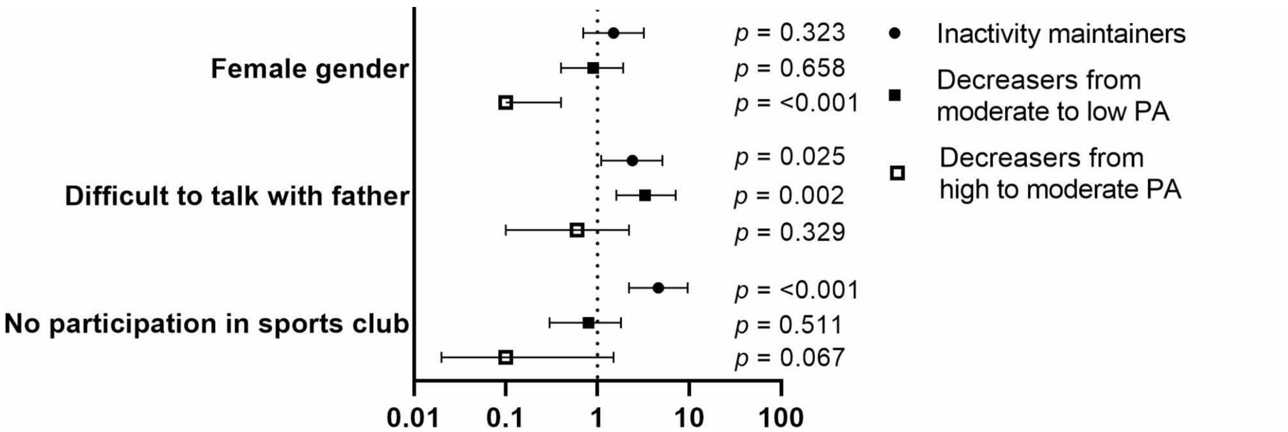
Discussion

The study aimed to determine the psychosocial, health behavioural and PA domain-related characteristics of different longitudinal PA patterns from adolescence to young adulthood. The patterns (i.e. groups with different PA development over time) were based on device-measured MVPA and formed via a novel data-driven method. Multilevel factors were found to characterise the

Table 2 Health behavioural characteristics compared between longitudinal physical activity patterns

	Mean age	All	Inactivity maintainers (A)	Activity maintainers (B)	Decreasers from moderate PA (C)	Decreasers from high PA (D)	Increasers (E)	*p*-value
Smoking (other than non-smoking), *n* (%)	15	14 (6)	6 (9)	3 (4)	5(8)	0	0	0.333
	19	34 (13)	14 (20)	6 (9)	12 (20)	2 (6)	0	0.036
Snuff use (other than no snuff use), *n* (%)	15	8 (3)	4 (6)	1 (1)	2 (3)	0	1 (5)	0.469
	19	25 (10)	6 (9)	4 (6)	7 (12)	7 (22)	1 (5)	0.155
Alcohol consumption at least once a month, *n* (%)	15	21 (9)	9 (13)	6 (9)	4 (7)	2 (7)	0	0.453
	19	167 (66)	45 (63)	49 (70)	36 (59)	24 (75)	13 (68)	0.533
Have been drunk at least twice, *n* (%)	15	25 (10)	11 (16)	8 (12)	3 (5)	2 (7)	1 (5)	0.268
	19	166 (66)	47 (66)	42 (60)	39 (64)	26 (81)	12 (63)	0.333
Eating a school meal every school day, *n* (%)	15	204 (82)	58 (85)	56 (81)	51 (84)	22 (73)	17 (85)	0.694
Eating breakfast every weekday morning, *n* (%)	15	165 (67)	42 (62)	48 (70)	40 (66)	21 (70)	14 (70)	0.866
	19	209 (83)	53 (76)	57 (81)	51 (84)	30 (94)	18 (95)	0.134
Daily consumption of fruits or/and vegetables, *n* (%)	15	110 (44)	26 (38)	36 (52)	23 (38)	15 (50)	10 (50)	0.348
	19	108 (43)	23 (32)	37 (53)	21 (34)	18 (56)	9 (47)	0.035
Fruit and vegetable consumption index, mean (SD)	15	9.1 (4.3)	8.0 (4.6)	9.9 (3.9)	8.5 (4.4)	10.6 (3.7)	10.0 (4.2)	ns
	19	9.3 (4.0)	7.7 (4.2)	10.6 (3.6)	8.7 (4.1)	10.8 (3.0)	10.0 (4.0)	A < B** A < D**
Sweets and sugared soft drinks consumption index, mean (SD)	15	6.0 (3.5)	5.9 (3.6)	6.1 (3.5)	6.6 (3.2)	4.9 (3.4)	5.9 (3.5)	0.240
	19	7.2 (3.4)	7.1 (3.4)	7.2 (3.6)	7.3 (3.0)	7.7 (3.7)	6.7 (3.5)	0.915
At least weekly energy drink consumption, *n* (%)	15	20 (8)	8 (12)	4 (6)	4 (7)	2 (7)	2 (10)	0.721
	19	27 (11)	5 (7)	7 (10)	4 (7)	8 (25)	3 (16)	0.065
Brushing teeth two times per day, *n* (%)	15	158 (64)	44 (65)	45 (65)	40 (66)	19 (63)	10 (50)	0.769
	19	174 (69)	48 (68)	49 (70)	40 (66)	24 (75)	13 (68)	0.915
Sleep duration on weekdays, mean hours (SD)	15	8.2 (0.8)	8.0 (0.8)	8.3 (0.7)	8.3 (0.8)	8.5 (0.6)	8.6 (0.8)	A < D* A < E*
	19	7.8 (0.9)	7.7 (0.9)	7.7 (1.0)	7.8 (0.9)	7.8 (0.8)	7.9 (0.6)	ns

Note: The identification of the longitudinal physical activity patterns was based on two valid accelerometry measurement periods of moderate-to-vigorous physical activity, and used a data-driven method (K-means for longitudinal data, KmL [25]) [5]. *p*-values have been assessed using the Chi-square test or Fisher's exact test (in cases of sparse data) for categorical variables. The Kruskal-Wallis test was used in analysing differences in mean values between PA patterns cross-sectionally (with post hoc Dunn's test adjusted by the Bonferroni correction for multiple tests). ns = non significant; PA = physical activity; SD = standard deviation; * $p < 0.05$; ** $p < 0.01$



Odds ratios (log-scale) with their 95% confidence intervals, calculated via a multinomial logistic regression analysis predicting belonging to longitudinal physical activity patterns. Comparisons of inactivity maintainers and decreaser groups with the combined group of activity maintainers and increasers. Adjusted for the measurement interval and the change in device wear-time between baseline and follow-up.

Fig. 1 Analysis stemming from exposure variables presented at baseline (mean age 15)

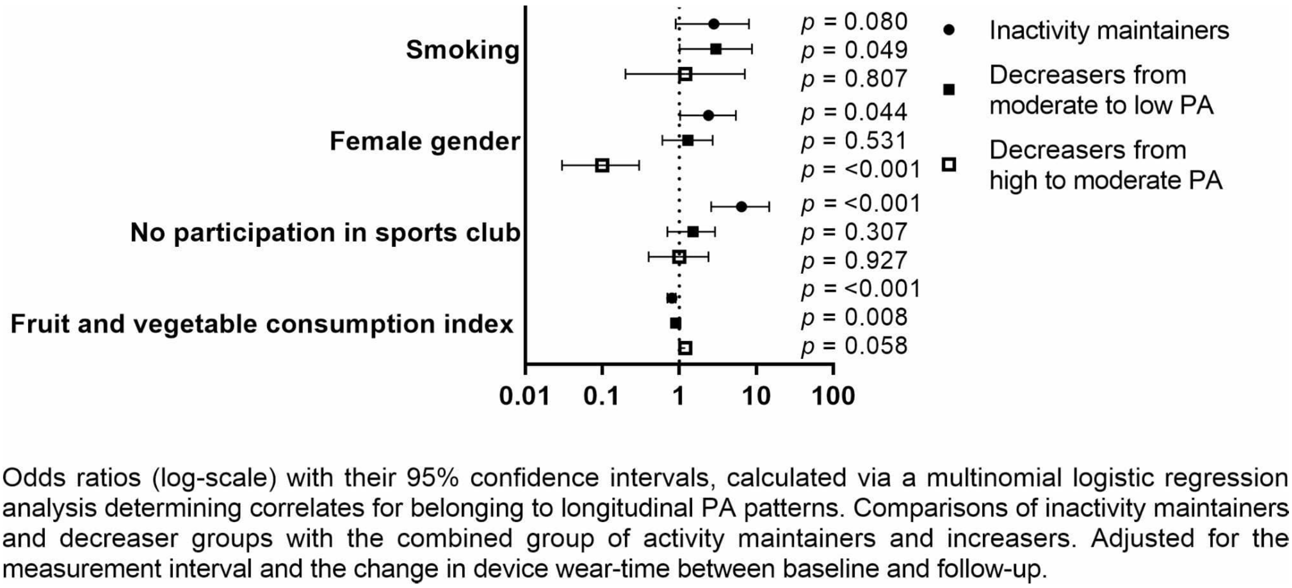


Fig. 2 Analysis stemming from exposure variables presented at follow-up (mean age 19)

PA patterns. At age 15, *gender, sports club participation*, and *communication difficulties with one's father* were the most important predictors for PA patterns. Correspondingly, at age 19, *gender, sports club participation*, and *fruit and vegetable consumption* were associated with longitudinal PA patterns.

A lack of sports club participation characterised *inactivity maintainers* throughout adolescence. Indeed, such non-participation showed the strongest association for belonging to this PA pattern. The result is in line with previous studies showing the relation between sports participation and maintained PA during adolescence [5, 9, 19]. Sports clubs have an important role in supporting maintained PA, including during early young adulthood, even if dropout from organised sports is common during adolescence [5, 34]. In Finland, sports clubs are typically based on voluntary civic activities at local level.

Surprisingly, *communication difficulties with the father* (but not with the mother) were related to increased odds of being a *decreaser from moderate to low PA* and also of being an *inactivity maintainer.* This implies that a father-adolescent relationship that supports open communication might be one determinant for sustained PA behaviour during adolescence. Note that we used only one question to assess the broad phenomenon, and that the association disappeared at age 19. One can suggest that analysis of the communication and relationship with parents would be a topic for future research on PA development during adolescence, since previous research has shown that parent-adolescent communication predicts adolescent MVPA one year later [35], and that communication difficulties pose a risk for decreased life-satisfaction [36–38]. Generally speaking, there has been a positive increasing trend in ease of communication with both parents over the 2000s, although communication with the mother has appeared to be easier than with the father [39, 40]. Future studies should examine whether communication with friends (including girl-/boyfriend) and siblings compensates for poorer communication with parents, especially during young adulthood. Further research could also encompass the extent to which a parent's divorce (and subsequent residential arrangements) and the adolescent's individual temperament alter the association between communication problems and PA patterns.

Feelings of *loneliness* at age 19 were more commonly reported by *inactivity maintainers* (14%) and by *decreasers from moderate to low PA* (16%) as compared to *increasers* (0%) and *decreasers from high to moderate PA* (0%). Because frequent loneliness was non-existent in some PA patterns, the loneliness variable did not fit into the logistic regression models. The association we found in cross tabulation is logical also when placed alongside a review study which provided evidence for the potential diminishing effect of loneliness on PA – but conversely, the potential value of PA in reducing loneliness [41].

From the multiple health behaviours analysed only *fruit and vegetable consumption* and *smoking* appeared among the multilevel correlates for PA patterns at age 19. Lower fruit and vegetable consumption was related to increased odds of belonging to both *inactivity maintainers* and *decreasers from moderate to low PA*, with smoking also being related to the decreaser group. These findings are more or less as expected, since both unhealthy and harmful behaviours tend to accumulate [42]. Moreover, the results here are in line with previous research indicating that fruit and vegetable consumption is higher among adolescents who are persistently active [43]. In another study exploring multiple health behaviours (but not dietary habits), smoking, and being drunk (the latter only for girls) at baseline (i.e. among 13- to 15-year-olds) were associated with increased odds of being an inactivity maintainer rather than an activity maintainer [19]. Similarly, smoking at a young adult age was more common among persistently sedentary participants than among their persistently active counterparts [44]. In our study, neither alcohol consumption nor binge drinking differed between the PA patterns, but the results are similar to previous studies insofar as smoking seems to be related to unfavourable PA development over time. According to a recent review study – which did not consider different longitudinal PA patterns – PA is positively associated with alcohol use among emerging adults (aged 18–25) but less consistently among adolescents [45]. However, methodological and contextual differences hinder comparison between the studies in question.

The decreasers from high to moderate PA constituted a relatively small group that could be characterised only by male gender. Maintained participation in sports clubs and also withdrawal from sports clubs (as opposed to 'never-participation', i.e. non-participation at either age 15 or 19) have previously been related to increased odds of being in this group of decreasers [5]. However, as compared to the other PA patterns detected, this decreaser group is less homogeneous, as shown by the relatively wide standard deviation in PA levels. These limit the possibility to form conclusions on the characteristics of this pattern. A similar pattern, involving a substantial decrease from high MVPA, has been found in a previous study by Kwon et al. [21], in which the male gender was more prevalent.

With regard to the other studied background variables, a lack of active commuting at either baseline or follow-up did not significantly differentiate between the PA patterns, even if sustained passive commuting has been related to maintained inactivity in the same study population (when inactive maintainers were compared to all the other groups together) [5]. This finding is a reminder that the time-varying nature of possible correlates should be also taken into account, and not just the associations at a single time point (see also [18, 46]).

Strengths and limitations

The main strengths of this study are the use of relatively large prospective data from a less-studied period of life (see also [2, 3, 6]), combining information from both survey and accelerometry to assess determinants and correlates for changed and maintained PA. Instead of grouping participants on the basis of predetermined PA levels, we used a novel data-driven method to identify genuinely heterogeneous PA patterns. The survey questions were mainly drawn from the international HBSC study, and the questions have thus been subject to validation [28].

The study encompassed multilevel predictors and correlates. However, it remains possible that certain other factors, operating for instance at the environmental level, might determine the differences between PA patterns. The data were limited to two measurements, and additional time points might have revealed more fluctuations in PA during adolescence. Furthermore, the number of persons in some of the PA patterns was small, which decreased the statistical power. Partly because of the sampling method (involving both sports clubs and schools), the young people in this study were more active than on average. However, this is also a strength, since it enabled a thorough analysis of PA and related factors for highly active young people in addition to those in the average population. Moreover, it can be claimed that the recruitment of the participants from six different regions of Finland (from 100 schools and 156 sports clubs) increased the quality of this study, even if the results are not directly generalisable to the entire Finnish age cohort in question.

Conclusions

This study contributed to the limited research base on PA development and its correlates during the transition to young adulthood. The results indicate that the relationship with one's father may play a role in supporting maintained PA during the adolescent years. Furthermore, a healthier diet and non-smoking as a young adult are associated with more favourable PA development. The study gives indications that although dropout from a sports club is common during adolescence [5, 34], organised sports still have a contribution in supporting favourable PA development when adolescents reach young adulthood.

While the study was successful in revealing some characteristics of the PA patterns, much variation exists in PA behaviour and related factors. Thus, the findings also demonstrate the complex and multidimensional nature of PA behaviour. This implies that there can be no 'one size fits all' in PA promotion; nevertheless, by addressing multiple different aspects, there may be better possibilities for preventing a decrease in PA and supporting the maintenance of healthy PA.

Abbreviations

CI	confidence interval
MET	metabolic equivalent
MVPA	moderate-to-vigorous physical activity
OR	odds ratio
PA	physical activity

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12889-023-17122-4.

Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

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Authors' contributions

SK is the principal investigator for the HPSC study, and was a major contributor in reviewing the manuscript together with TV. TA designed and conducted the analyses and drafted the manuscript, HV was responsible for processing the accelerometer data, and JK and JV advised on the statistical aspects of the study. TV, OH, RK, JK, JP, KS, KT, AU, MV, HV, and SK critically reviewed the final manuscript. All the authors contributed to the design of the work, and read and approved the final manuscript.

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Data Availability

The data underlying this article cannot be shared publicly since they contain confidential personal details and health information. The data will be shared on reasonable request to the principal investigator (sami.p.kokko@jyu.fi).

Declarations

Ethics approval and consent to participate

The HPSC study was conducted in accordance with the Declaration of Helsinki, and received ethical approval from the Ethics Committee of the Healthcare District of Central Finland (20.12.2012 (23 U/2012), 15.12.2016). Written informed consent was obtained from the participants, and also from a guardian when the participant was aged under 18. The permission notification included detailed information on the study, plus notification on the right of participants to refuse participation, and to withdraw their consent without giving a reason.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Author details

[1]Faculty of Sport and Health Sciences, Research Centre for Health Promotion, University of Jyväskylä, PL 35, Jyväskylä FI-40014, Finland
[2]UKK Institute of Health Promotion Research, Kaupinpuistonkatu 1, FI-33500 Tampere, Finland
[3]Faculty of Medicine and Health Technology, Tampere University, Tampere, Finland
[4]Paavo Nurmi Centre & Unit for Health and Physical Activity, University of Turku, Kiinamyllykatu 10, FI-20520 Turku, Finland
[5]Medical Research Center (MRC), University of Oulu and University Hospital of Oulu, Oulu, Finland
[6]Department of Sports and Exercise Medicine, Oulu Deaconess Institute Foundation sr, P.O. Box 365, FI-90101 Oulu, Finland
[7]Research Unit of Population Health, University of Oulu, Oulu, Finland
[8]Department of Mathematics and Statistics, University of Jyväskylä, P.O. Box 35, FI-40014 Jyväskylä, Finland
[9]Tampere Research Center of Sports Medicine, Kaupinpuistonkatu 1, FI-33500 Tampere, Finland
[10]Faculty of Sport and Health Sciences, University of Jyväskylä, PL 35, FI-40014 Jyväskylä, Finland
[11]Department of Clinical Physiology and Nuclear Medicine, Kuopio University Hospital, Kuopio, Finland
[12]Kuopio Research Institute of Exercise Medicine, Haapaniementie 16, FI-70100 Kuopio, Finland
[13]Clinic for Sports and Exercise Medicine, Foundation for Sports and Exercise Medicine, Mäkelänkatu 47, FI-00550 Helsinki, Finland
[14]Department of Sports and Exercise Medicine, University of Helsinki, Clinicum, Finland
[15]Finnish Institute for High Performance Sport KIHU, Jyväskylä Finland, Rautpohjankatu 6, FI-40700 Jyväskylä, Finland

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Publisher's Note

III

LONGITUDINAL PHYSICAL ACTIVITY PATTERNS AND THE DEVELOPMENT OF CARDIOMETABOLIC RISK FACTORS DURING ADOLESCENCE

by

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ORIGINAL ARTICLE

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Longitudinal physical activity patterns and the development of cardiometabolic risk factors during adolescence

Tuula Aira[1] | **Sami Petteri Kokko**[1] | **Olli Juhani Heinonen**[2] | **Raija Korpelainen**[3,4,5] | **Jimi Kotkajuuri**[6] | **Jari Parkkari**[7,8] | **Kai Savonen**[9,10] | **Kerttu Toivo**[7] | **Arja Uusitalo**[11,12] | **Maarit Valtonen**[13] | **Jari Villberg**[1] | **Onni Niemelä**[14] | **Henri Vähä-Ypyä**[15] | **Tommi Vasankari**[15,16]

[1]Faculty of Sport and Health Sciences, Research Centre for Health Promotion, University of Jyväskylä, Jyväskylä, Finland
[2]Paavo Nurmi Centre & Unit for Health and Physical Activity, University of Turku, Turku, Finland
[3]Medical Research Center (MRC), University of Oulu and University Hospital of Oulu, Oulu, Finland
[4]Department of Sports and Exercise Medicine, Oulu Deaconess Institute Foundation sr., Oulu, Finland
[5]Center for Life Course Health Research, University of Oulu, Oulu, Finland
[6]Department of Mathematics and Statistics, University of Jyväskylä, Jyväskylä, Finland
[7]Tampere Research Center of Sports Medicine, Tampere, Finland
[8]Faculty of Sport and Health Sciences, University of Jyväskylä, Jyväskylä, Finland
[9]Department of Clinical Physiology and Nuclear Medicine, Kuopio University Hospital, Kuopio, Finland
[10]Kuopio Research Institute of Exercise Medicine, Kuopio, Finland
[11]Clinic for Sports and Exercise Medicine, Foundation for Sports and Exercise Medicine, Helsinki, Finland
[12]Department of Sports and Exercise Medicine, Clinicum, University of Helsinki, Helsinki, Finland
[13]Research Institute for Olympic Sports, Jyväskylä Finland, Jyväskylä, Finland
[14]Medical Research Unit and Department of Laboratory Medicine, Seinäjoki Central Hospital and University of Tampere, Tampere, Finland
[15]UKK Institute of Health Promotion Research, Tampere, Finland
[16]Faculty of Medicine and Health Technology, Tampere University, Tampere, Finland

Correspondence
Tuula Aira, Faculty of Sports and Health Sciences, University of Jyväskylä, PL 35, FI-40014 Jyväskylä, Finland.
Email: tuula.m.aira@jyu.fi

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Purpose: To examine the associations between longitudinal physical activity (PA) patterns and the development of cardiometabolic risk factors from adolescence to young adulthood.

Methods: This cohort study encompassed 250 participants recruited from sports clubs and schools, and examined at mean age 15 and 19. Device-measured moderate-to-vigorous PA was grouped into five patterns (via a data-driven method, using *inactivity maintainers* as a reference). The outcomes were: *glucose*, *insulin*, *homeostasis model assessment for insulin resistance* (*HOMA-IR*), *total cholesterol*, *HDL and LDL cholesterol*, *triglycerides*, *blood pressure*, and *body mass index* (*BMI*). Linear growth curve models were applied with adjustment for sex,

age, fruit/vegetable consumption, cigarette/snuff use, and change in the device wear-time.
Results: Insulin and BMI increased among *decreasers from moderate to low PA* (β for insulin 0.23, 95% CI 0.03–0.46; β for BMI 0.90; CI 0.02–1.78). The concentration of HDL cholesterol decreased (β −0.18, CI −0.31 to −0.05) and that of glucose increased (β 0.18, CI 0.02–0.35) among *decreasers from high to moderate PA*. By contrast, among *increasers*, blood pressure declined (systolic β −6.43, CI −12.16 to −0.70; diastolic β −6.72, CI −11.03 to −2.41).
Conclusions: Already during the transition to young adulthood, changes in PA are associated with changes in cardiometabolic risk factors. Favorable blood pressure changes were found among PA *increasers*. Unfavorable changes in BMI, insulin, glucose, and HDL cholesterol were found in groups with decreasing PA. The changes were dependent on the baseline PA and the magnitude of the PA decline.

KEYWORDS
accelerometry, adolescent, blood pressure, body mass index, insulin resistance, young adults

1 | INTRODUCTION

Physical activity (PA) decreases the risk for chronic diseases such as cardiovascular diseases and type 2 diabetes,[1,2] which are among the leading causes of death worldwide.[3] Although the full cardiometabolic benefits of PA appear over the course of decades, some health outcomes have been observed at childhood and adolescence.[4–7] However, the latter observations are based on a limited number of studies using heterogeneous methods.[4,6]

The associations between PA and cardiometabolic outcomes in prospective studies are traditionally examined either by analyzing (i) *baseline PA* in relation to a follow-up cardiometabolic outcome or change in the outcome, or (ii) the association between a *change in PA* and a change in the cardiometabolic outcome.[4,5,8] However, neither of these approaches take account of the fact that distinct patterns of PA evolution might result in different cardiometabolic outcomes, depending on the *baseline PA level*, and also on the *magnitude of the change in PA*. Thus, there is a need to analyze differences in cardiometabolic risk between subgroups of adolescents with different PA changes over time (also, see Ref.[9]).

A growing number of studies have identified distinct longitudinal PA patterns (or trajectories) during adolescence, identifying, for example, groups maintaining high or low activity, and patterns of decreasing and increasing activity (as we did in our previous study when we created the PA groups used in the current study[10]).[11,12] Only a few have gone further and focused on possible differences in health outcomes between groups representing different PA patterns.[13–18] Some of these studies have used objective methods for PA assessment[15–17] or applied data-driven methods (algorithm- or model-based) to identify distinct PA patterns.[14,15,17] PA assessment via accelerometry is recommended over self-reported measurements, since it enables more reliable determination of e.g. the duration and intensity of the PA.[19] At the same time, data-driven methods are better able to identify genuinely heterogeneous PA patterns than are subjective methods (such as splitting into quartiles or using pre-determined levels of PA). To our knowledge there are no studies on simultaneous cardiometabolic risk factors between various PA patterns, with PA assessment conducted via accelerometry, and with patterns grouped via a data-driven method. Existing studies fulfilling the methodological requirements mentioned above have examined the association of PA patterns with the accumulation of body adiposity[17] and obesity development,[15] but blood biomarkers have not been studied in a similar manner. It should also be noted that the follow-up periods used in previous studies have varied: Oh et al.[17] followed adolescents between the ages 15 and 23, while the study of Kwon et al.[15] set the baseline at childhood (with follow-up from 5 to 19 years).

Our aim was to examine how longitudinal PA patterns (based on moderate-to-vigorous PA (MVPA) and exhibited by *inactivity maintainers*, *activity maintainers*, *decreasers from moderate to low PA*, *decreasers from high to moderate PA*, and *increasers*)[10] were associated with the evolution of cardiometabolic risk factors (blood lipids, glucose metabolism, blood pressure, and body mass index (BMI)), from adolescence (mean age 15) to young adulthood (mean age

19). The *inactivity maintainers* group was used as a reference. We hypothesized that decreasing PA is positively and increasing PA inversely associated with cardiovascular risk factor development, at least in terms of some risk factors.

2 | MATERIALS AND METHODS

2.1 | Study design and participants

This observational cohort study was part of the Health Promoting Sports Club study, conducted in 2013–2014 and 2017–2018.[20] At baseline, the participants (mean age 15 years) were recruited from sports clubs and schools in six large cities and surrounding communities, in different parts of Finland (Figure 1). The sports clubs represented the 10 most popular team and individual sports disciplines: basketball, floorball, ice hockey, soccer, cross-country skiing, gymnastics, orienteering, skating, swimming, and track and field (for more details of the study protocol see Ref.[20,21]).

The HPSC study was conducted in accordance with the Declaration of Helsinki, and received ethical approval from the Ethics Committee of the Healthcare District of Central Finland 20.12.2012 (23 U/2012), 15.12.2016. Written consent was required from the participants, and also from a guardian when the participant was aged under 18.

The participants first took part in electronic surveys on current health behaviors and health status. On the basis of power calculations, randomly selected participants were also invited to participate in pre-participation screening in one of the six national Centres of Excellence in Sports and Exercise Medicine. The pre-participation screening included screening by a physician and a fasting blood sample.[20] Instructions were also given on a hip-worn accelerometer, which the participants wore for 7 consecutive days during waking hours, except when bathing or during water activities. Surveys, clinical examinations and PA measurements were all conducted during the same season of the year.

Nearly two-thirds (65% of the eligible participants) of the baseline participants ($n = 583$) also took part in the study in 2017–2018 ($n = 371$) with similar measurements to those at baseline. The mean difference between the baseline and follow-up measurements was 3.8 years (SD 0.4, min 2.8, max. 5.1). In total, 254 participants provided valid accelerometer data and written consent for both measurement points (for more details, see Ref.[10]). Participants who were diagnosed as patients with type 1 diabetes were excluded ($n = 4$) as were also swimmers, who were not able to use the accelerometer during their swimming training (Figure 1). Out of those 250 participants, 239–250 at baseline and 242–250 at follow-up had valid data on cardiometabolic risk outcomes.

2.2 | Physical activity

Physical activity was measured via a Hookie accelerometer (AM20 Activity meter, Hookie Technologies Ltd.),

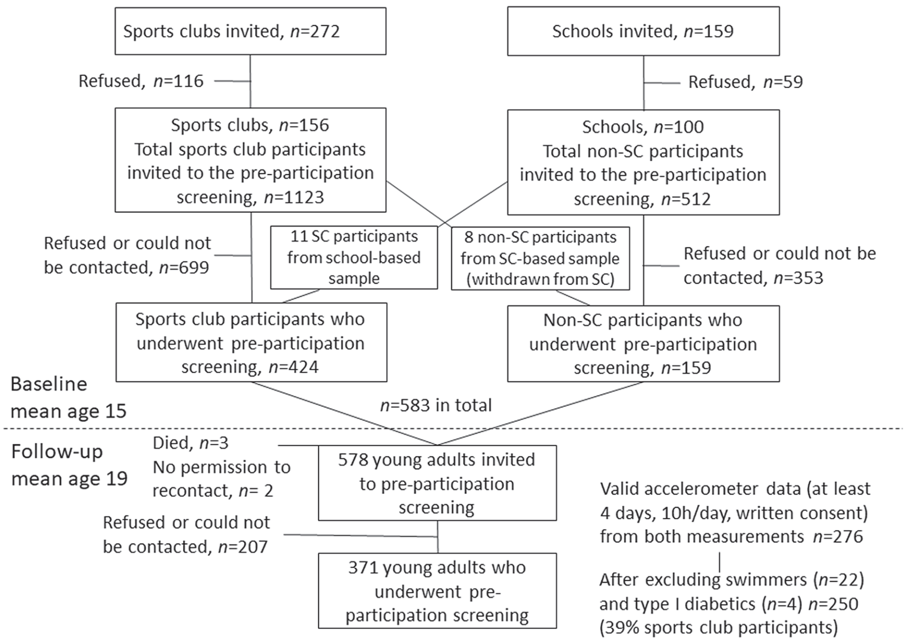

FIGURE 1 Flow chart of the data collection and study sample.

which collected and stored tri-axial data as actual g-units with a 100 Hz sampling frequency. The Hookie accelerometer has been shown to be a valid measurement tool for both adolescents[22] and adults.[23] The data were analyzed in units of 6 s duration. Continuous quiescent time exceeding 30 min was taken to indicate nonwear of the device, as recommended also by others.[24] The PA analysis was based on mean amplitude deviation analyses (MAD), calculated from a resultant tri-axial raw acceleration signal, and converted to metabolic equivalents (METs).[23,25] The epoch-wise MET values were further smoothed by calculating the 1 min exponential moving average MET value for each epoch time point. Moderate-to-vigorous PA (MVPA) was defined as an MET value of ≥3.0.[22] For a valid measurement, at least 10 h per day and at least 4 days per week were required, as was also informed consent for the measurement.

The formulation of the longitudinal PA patterns has previously been described in detail.[10] Based on two valid MVPA measurement periods, a k-means algorithm for longitudinal data (KmL)[26] was applied to identify homogenous subgroups, that is, clusters that were as heterogeneous as possible in comparison with each other. The PA patterns were: *inactivity maintainers*, *activity maintainers*, *decreasers from moderate (to low) PA*, *decreasers from high (to moderate) PA*, *increasers* (Figure 2).

2.3 | Clinical examination

In the pre-participation screening, trained personnel (with a specialization in healthcare) measured the height and weight (wearing light clothes without shoes) of the participants to the nearest 0.5 cm and 0.1 kg. BMI was calculated as weight (kg)/height (m)^2. The participant was seated, and after at least 5 min of rest, blood pressure was measured via a validated, cuff-style oscillometric (automated) device.[27] A second measurement was taken at an interval of 1 min. A third measurement was obtained if there was more than 10 mm Hg difference in systolic or diastolic pressure between the first and second measurement. The average of two (or three) measurements was used in the analyses.

2.4 | Laboratory analyses

Venous blood samples were taken after participants had fasted for at least 10 h. Serum and plasma were separated by centrifugation (2000 g for 10 min) and stored at −75°C prior to analysis. Concentrations of fasting plasma glucose, serum total cholesterol, high- and low-density cholesterol (HDL, LDL), and triglyceride were analyzed using standard enzymatic methods on a Cobas c702 clinical chemistry analyzer (Roche Diagnostics). Serum insulin concentrations were determined using electrochemiluminescence technology on Cobas e801, according to the instructions of the manufacturer (Roche Diagnostics). All measurements were carried out in an SFS-EN ISO 15189:2013 accredited laboratory.

The homeostasis model assessment for insulin resistance (HOMA-IR) was assessed via the formula: (fasting serum insulin (mU/L) × fasting plasma glucose (mmol/L))/22.5.[28]

2.5 | Other variables

Participants reported their smoking, alcohol consumption, snuff use, and eating behavior in the electronic survey. Combined information covering at least weekly cigarette and/or snuff use was applied in the analysis (yes/no). Because fruit and vegetable intake is associated with a reduced risk for cardiovascular disease[29] and reflects healthy eating overall, a fruit and vegetable index[30] was applied in the analyses. The index ranged from 0 to 14, where value 0 represented no fruit and vegetable consumption and value 14 consumption of both fruit and vegetables at least once a day (for more details, see Ref.[30,31]). The assessment of family affluence was based on a previously validated Family Affluence Scale score, which was calculated from participants' answers to questions on four common consumption indicators of material deprivation (cars, bedrooms, computers, vacations).[32]

2.6 | Statistical analyses

To characterize the PA patterns cross-sectionally,[33] the Kruskal–Wallis test (with post hoc Dunn's test, adjusted by the Bonferroni correction for multiple tests) and the Chi-square test were used to reveal the differences in mean values and in frequencies. The significance of the change over time was calculated by the Wilcoxon signed rank test. The independent samples *t*-test and Mann Whitney U test were performed in the loss-to-follow up analysis. All the descriptive data analyses were conducted using SPSS version 26.

To further study the differences between PA patterns with regard to cardiometabolic risk factors, linear growth curve analyses (nlme package in R Studio; version 4.0.3)[34] were conducted. The baseline level and the slope (rate of change over time) of each cardiometabolic risk factor were explained by (in addition to the PA pattern) sex, age, fruit and vegetable consumption, snuff and/or cigarette use, plus the change in the device wear-time between the

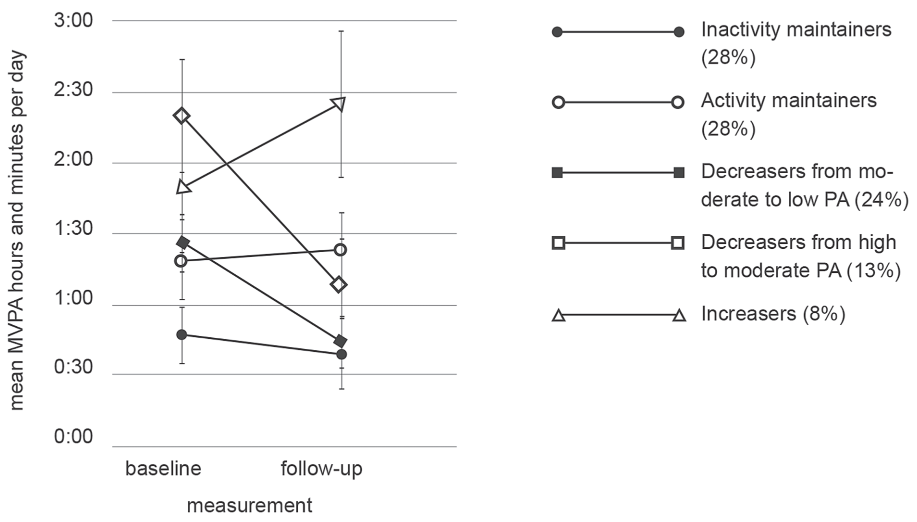

FIGURE 2 Longitudinal physical activity patterns (the data are mean and standard deviation).[10]

baseline and follow-up measurements (to eliminate the effect on the results of differences in device usage time). The change in cardiometabolic risk factors over time by PA pattern was also examined (i.e., with time nested within participant as a random effect). The growth curve analysis accommodates missing data by creating estimates based on all available data for each participant. Moreover, the baseline values of the outcome are reflected in the intercept of the model, ensuring correction of any possible regression to the mean.

The outcome variables triglyceride, HOMA-IR, and insulin were log-transformed using $\log(x+1)$ transformation to improve the normal distribution of the residuals. A multiple of the identity positive-definite matrix (PdIdent) was set as a correlation structure in all the models for the same reason. Age was centred at 15, with age 15 corresponding to time = 0. Additional analyses were performed by adjusting the cardiometabolic risk factors also for BMI (centred) and for the season of the year when measured, in order to assess whether the associations were independent of BMI and seasonal variation. The significance level was set at $p < 0.05$ in all the statistical tests.

3 | RESULTS

The study sample was 60% female and at baseline two thirds (68%) of the participants lived in families with high affluence (Table 1). At follow-up, 64% of the young adults were studying (39% in a general upper secondary school, 9% in a vocational school, and 16% in a university or university of applied sciences), while 20% had entered working life. Table 1 illustrates more characteristics of the participants by PA patterns, including health behaviors, and the amount of MVPA.

The study participants and those lost to follow-up at the second measurement did not differ in any of the studied baseline cardiometabolic risk factors, or in terms of MVPA or family affluence (see Table S1). However, males, and those who reported lower school achievement, were more likely not to participate in the post-measurement (see Table S1). Table 2 presents the differences in cardiometabolic risk factors between PA patterns at baseline, at follow-up, and in development over time.

3.1 | Growth curve analyses

To further study the differences in cardiometabolic risk factors between PA patterns, growth curve analyses were conducted with adjustment for sex, age, fruit and vegetable consumption, snuff and/or cigarette use, plus the change in the device wear-time (see Table 3, Table S2 with confidence intervals).

3.2 | Baseline

The *decreasers from moderate to low PA* had lower baseline values in insulin, HOMA-IR and BMI as compared to the *inactivity maintainers* (the reference group) (Table 3, Figure 3). The *decreasers from high to moderate PA* had lower glucose, insulin and HOMA-IR levels, and higher HDL cholesterol at baseline as compared to the corresponding levels among the *inactivity maintainers*. There was no significant difference in the baseline levels of any of the studied cardiometabolic risk parameters between

TABLE 1 Characteristics of the study participants by physical activity patterns.

	All	Inactivity maintainers (A)	Activity maintainers (B)	Decreasers from moderate to low PA (C)	Decreasers from high to moderate PA (D)	Increasers (E)	*p*
***n* (%)**	250 (100)	69 (28)	69 (28)	60 (24)	32 (13)	20 (8)	
Age, mean years (SD)							
Baseline	15.5 (0.6)	15.6 (0.5)	15.5 (0.6)	15.3 (0.5)	15.5 (0.5)	15.4 (0.5)	0.138
Follow-up	19.4 (0.6)	19.4 (0.7)	19.4 (0.7)	19.2 (0.7)	19.5 (0.6)	19.5 (0.5)	0.130
Males, *n* (%)	100 (40)	19 (28)	24 (35)	22 (37)	26 (81)	9 (45)	<0.001
MVPA mean/day: hours and minutes (SD)							
Baseline	1:22 (0:33)	0:47 (0:12)	1:19 (0:17)	1:26 (0:12)	2:20 (0:24)	1:50 (0:28)	A < B–E <0.001, B < D <0.001, B < E 0.004, C < D <0.001
Follow-up	1:05 (0:34)	0:39 (0:15)	1:24 (0:15)	0:44 (0:11)	1:07 (0:21)	2:25 (0:31)	A < B,D,E <0.001, B > D 0.041, B < E 0.047, C < B,D,E <0.001, D < E <0.001
MVPA change, mean minutes (SD)	−16.5 (37.7)	−7.9 (19.4)	5.2 (22.7)	−40.9 (17.3)	−67.8 (29.7)	34.7 (44.3)	
Education & employment status, *n* (%)							
Follow-up							
Studying	159 (64)	40 (59)	46 (67)	44 (73)	18 (56)	11 (58)	0.768[a]
Working	50 (20)	16 (24)	13 (19)	9 (15)	8 (25)	4 (21)	
Other[b]	39 (16)	12 (17)	10 (15)	7 (12)	6 (19)	4 (21)	
Living with parents, *n* (%)							
Follow-up	170 (68)	48 (70)	47 (68)	38 (63)	23 (72)	14 (74)	0.885
Living in urban area, *n* (%)							
Baseline	161 (66)	35 (53)	49 (71)	42 (70)	21 (70)	14 (70)	0.169
Follow-up	197 (79)	51 (74)	57 (83)	49 (82)	27 (84)	13 (68)	0.455
Self-reported school grade average: good to excellent (grades 8–10 in grading 4–10), *n* (%)							
Baseline	203 (83)	51 (77)	57 (83)	51 (85)	27 (90)	17 (85)	0.643
High family affluence, *n* (%)							
Baseline	152 (62)	36 (55)	44 (64)	38 (63)	22 (73)	12 (60)	0.505
Reached menarche or Tanner stage P4, *n* (%)							
Baseline	238 (95)	67 (97)	66 (96)	56 (93)	29 (91)	20 (100)	0.529

TABLE 1 (Continued)

	All	Inactivity maintainers (A)	Activity maintainers (B)	Decreasers from moderate to low PA (C)	Decreasers from high to moderate PA (D)	Increasers (E)	*p*
Snuff and/or cigarette use at least weekly, *n* (%)							
Baseline	7 (3)	4 (6)	0	3 (5)	0	0	0.154
Follow-up	24 (10)	8 (12)	4 (6)	8 (13)	3 (9)	1 (5)	0.626
Alcohol consumption at least weekly, *n* (%)							
Baseline	1 (0.4)	0	0	1 (2)	0	0	
Follow-up	20 (8)	5 (7)	6 (9)	5 (8)	3 (9)	1 (5)	0.995
Fruit & vegetable consumption index, mean (SD)							
Baseline	9.1 (4.3)	7.9 (4.6)	9.9 (3.9)	8.6 (4.4)	10.6 (3.7)	10.0 (4.2)	ns
Follow-up	9.2 (4.0)	7.5 (4.2)	10.6 (3.6)	8.6 (4.0)	10.8 (3.0)	10.0 (3.6)	A < B <0.001, A < D 0.003, C < D 0.039

Note: *p*-values have been assessed using Chi-square test or Fisher's exact test (in cases of sparse data) for categorical variables. The Kruskal-Wallis test was used in analyzing differences in mean values between PA patterns cross-sectionally (with post hoc Dunn's test adjusted by the Bonferroni correction for multiple tests).

Abbreviation: PA, physical activity.

[a]The *p*-value represents the difference between the groups in bold font (studying, working, other) and PA patterns.

[b]For example for those who are unemployed, temporarily laid off, or doing military service.

the *activity maintainers* and the reference group, or between the *increasers* and the reference group (Table 3).

3.3 | Change over time

The development over time in HOMA-IR and in insulin among the *decreasers from moderate to low PA* differed from the corresponding development among the *inactivity maintainers*, hence showing unchanged HOMA-IR (vs. a decrease among the inactivity maintainers), and increased insulin (vs. a decrease among the inactivity maintainers; see Table 3, Figure 3). BMI increased among the *decreasers from moderate to low PA*, whereas BMI was essentially unchanged (stable) among the *inactivity maintainers*.

The decrease over time in systolic and diastolic blood pressure among the *increasers* differed from the fairly stable trend among the *inactivity maintainers* (Table 3, Figure 3). There was no difference in the development of the cardiometabolic risk factors over time between the *activity maintainers* and the *inactivity maintainers*.

3.4 | Adjustment for BMI and the measurement season

After adjusting the analyses for BMI, the results mainly remained unchanged. However, some associations no longer reached statistical significance, namely HOMA-IR and insulin at baseline among the *decreasers from high to moderate PA*, and the rate of change in insulin among the *decreasers from moderate to low PA* (see Table S3). Adjustment for the measurement season did not alter the main results (Table S4).

4 | DISCUSSION

This longitudinal cohort study indicated changes in cardiometabolic risk from adolescence to young adulthood (from age 15 to 19) that were associated with changes in PA. The results also highlighted the importance of the baseline level and of the magnitude of the PA change. Unfavorable changes in insulin and BMI occurred among *decreasers from moderate to low PA*, as compared to those who maintained a relatively low level of PA over time. There were also unfavorable changes in glucose and HDL cholesterol among *decreasers from high to moderate PA*. By contrast, among *increasers*, there were favorable changes in systolic and diastolic blood pressure, both of which decreased over time.

The changes in cardiometabolic risk factors were relatively small, suggesting no immediate cause for

TABLE 2 Cardiometabolic risk factors at baseline and follow-up across PA patterns (mean (SD)).

	All (women $n = 144$–150, men $n = 95$–100)		Inactivity maintainers (A)		Activity maintainers (B)		Decreasers from moderate to low PA (C)		Decreasers from high to moderate PA (D)		Increasers (E)		*p* (adj.) for differences between PA patterns	
	Baseline	Follow-up	Baseline	Follow-up	Baseline	Follow-up	Baseline	Follow-up	Baseline	Follow-up	Baseline	Follow-up	Baseline	Follow-up
Glucose (mmol/L)	**4.94** (0.33)	**4.77***** (0.38)	**4.95** (0.28)	**4.68***** (0.33)	**4.93** (0.40)	**4.78*** (0.40)	**4.93** (0.32)	**4.79*** (0.38)	4.95 (0.29)	4.87 (0.40)	4.97 (0.25)	4.78 (0.36)	ns	ns
Insulin (mU/L)	**11.42** (5.31)	**9.72***** (4.48)	**13.33** (6.55)	**10.56***** (5.23)	**11.42** (5.37)	**9.57*** (5.23)	10.73 (4.00)	10.50 (4.98)	**9.63** (3.66)	**7.82**** (2.38)	9.70 (4.01)	8.21 (4.40)	**D < A***	ns
HOMA-IR	**2.53** (1.25)	**2.08***** (1.02)	**2.95** (1.53)	**2.22***** (1.15)	**2.53** (1.28)	**2.05**** (0.84)	2.37 (0.95)	2.27 (1.23)	**2.12** (0.82)	**1.69**** (0.52)	2.17 (0.98)	1.75 (0.93)	**D < A***	ns
Cholesterol (mmol/L)	3.83 (0.67)	3.87 (0.79)	3.86 (0.70)	3.88 (0.76)	3.95 (0.76)	3.97 (0.83)	3.82 (0.58)	3.98 (0.82)	3.57 (0.59)	3.49 (0.73)	3.72 (0.53)	3.77 (0.58)	ns	**D < B,C***
LDL cholesterol (mmol/L)	1.98 (0.58)	1.95 (0.64)	1.99 (0.62)	1.91 (0.61)	2.09 (0.64)	2.03 (0.64)	1.94 (0.54)	2.03 (0.71)	1.84 (0.51)	1.81 (0.65)	1.86 (0.41)	1.84 (0.50)	ns	ns
HDL cholesterol (mmol/L)	1.46 (0.30)	1.50 (0.35)	1.46 (0.38)	1.53 (0.38)	1.46 (0.32)	1.54 (0.36)	1.49 (0.28)	1.50 (0.33)	**1.41** (0.26)	**1.31**** (0.29)	1.47 (0.33)	1.59 (0.32)	ns	**D < A,B,E***
Triglycerides (mmol/L)	**0.85** (0.40)	**0.92*** (0.45)	0.92 (0.44)	0.98 (0.45)	0.87 (0.40)	0.89 (0.51)	**0.79** (0.31)	**0.99**** (0.44)	0.72 (0.26)	0.82 (0.82)	0.87 (0.87)	0.77 (0.31)	ns	ns
Systolic blood pressure (mm Hg)	**117.1** (10.89)	**121.2***** (11.89)	**116.4** (11.50)	**121.3***** (12.48)	116.6 (10.19)	118.5 (11.31)	**116.0** (10.69)	**121.9***** (11.78)	**120.3** (11.31)	**127.4**** (10.65)	119.4 (10.80)	118.4 (11.01)	ns	**A,E < D*** **B < D****
Diastolic blood pressure (mm Hg)	**67.4** (7.12)	**72.6***** (7.94)	**68.8** (6.17)	**74.4***** (8.60)	**67.5** (7.12)	**71.9***** (7.09)	**66.3** (6.77)	**73.7***** (7.45)	**66.2** (9.09)	**72.9***** (8.34)	66.7 (7.54)	65.7 (5.43)	ns	**E < A,C***** **E < B**** **E < D***
Body mass index (kg/m^2)	**21.1** (2.82)	**23.2***** (3.32)	**21.8** (3.05)	**23.6***** (3.91)	**21.5** (2.90)	**23.4***** (3.41)	**20.4** (2.83)	**23.1***** (3.32)	**20.8** (2.08)	**23.0***** (1.86)	**20.5** (2.06)	**22.1***** (2.37)	**C < A***	ns

Note: The Kruskal–Wallis test was used in analyzing the differences in mean values between physical activity patterns cross-sectionally (with post hoc Dunn's test adjusted by the Bonferroni correction for multiple tests), and the Wilcoxon Signed Rank test was used to analyze differences over time. Numbers in bold indicate significant differences over time, and letters in bold (in the last two columns) indicate significant difference between physical activity patterns. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

Abbreviations: HDL, high-density lipoprotein; HOMA-IR, homeostasis model assessment for insulin resistance; LDL, low-density lipoprotein; PA, physical activity.

TABLE 3 Growth curve models for cardiometabolic risk factors (assessing baseline level and change over time).

	Glucose (mmol/L)	Insulin (mU/L)[a]	HOMA-IR[a]	Cholesterol (mmol/L)	LDL cholesterol (mmol/L)	HDL cholesterol (mmol/L)	Triglycerides (mmol/L)[a]	Systolic BP (mm Hg)	Diastolic BP (mm Hg)	Body mass index
	β	β	β	β	β	β	β	β	β	β
Baseline level										
Intercept	**5.22*** **	**16.07*** **	**1.48*** **	**3.77*** **	**2.10*** **	**1.23*** **	**0.89*** **	**124.13*** **	**71.28*** **	**21.39*** **
PA pattern B	−0.12	−0.21	−0.19	0.10	0.09	0.01	0.005	1.82	0.06	−0.36
PA pattern C	−0.15	**−0.33** **	**−0.25** **	−0.14	−0.12	0.10	−0.12	−2.38	−3.71	**−2.13** **
PA pattern D	**−0.31***	**−0.29***	**−0.24***	0.05	−0.08	**0.24***	−0.10	−4.20	−3.00	−1.39
PA pattern E	−0.14	−0.29	−0.18	−0.19	−0.22	−0.02	0.04	6.71	4.55	−0.76
Sex (female)	**−0.23*** **	0.04	−0.01	**0.33*** **	0.13	**0.22*** **	0.01	**−12.02*** **	−1.21	−0.23
Age (15 years)	−0.04	−0.003	−0.002	0.06	0.03	0.01	0.02	1.55	**2.03** **	**0.54***
Rate of change										
Time	−0.09	−0.20	−0.18	−0.19	−0.17	0.04	−0.05	−0.85	−2.14	−0.22
Time by PA pattern B	0.10	0.11	0.11	−0.001	0.02	0.002	−0.03	−2.91	−1.05	0.14
Time by PA pattern C	0.11	**0.23***	**0.18***	0.13	0.13	−0.06	0.07	0.81	1.77	**0.90***
Time by PA pattern D	**0.18***	0.09	0.10	−0.15	0.03	**−0.18** **	0.01	1.59	0.60	0.31
Time by PA pattern E	0.13	0.08	0.03	0.08	0.09	0.06	−0.07	**−6.43***	**−6.72** **	−0.38

Note: Linear growth curve models, adjusted for change in the device wear-time, fruit and vegetable consumption, and weekly cigarette and/or snuff use. The intercept in the models represents the baseline level (mean) of the risk factor in the reference group (inactivity maintainers), when all the exposure variables are 0—in other words, among men, at age 15 (since age was centred), when fruit and vegetable consumption and weekly cigarette/snuff use were 0. *Time* represents the impact of time (mean slope) on the risk factors between baseline and follow-up in the reference group (inactivity maintainers), and *time by PA pattern* (B,C,D,E) the corresponding rate of change in the other PA patterns as compared to the rate of change in the reference group.

Abbreviations: B, activity maintainers; BP, blood pressure; C, decreasers from moderate to low PA; D, decreasers from high to moderate PA; E, increasers; HDL, high-density lipoprotein; HOMA-IR, homeostasis model assessment-insulin resistance; LDL, low-density lipoprotein; PA, physical activity; β, unstandardized regression coefficients.

[a]Back-transformation from the natural logarithm($\log(x+1)$); numbers in bold indicate significant differences, *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

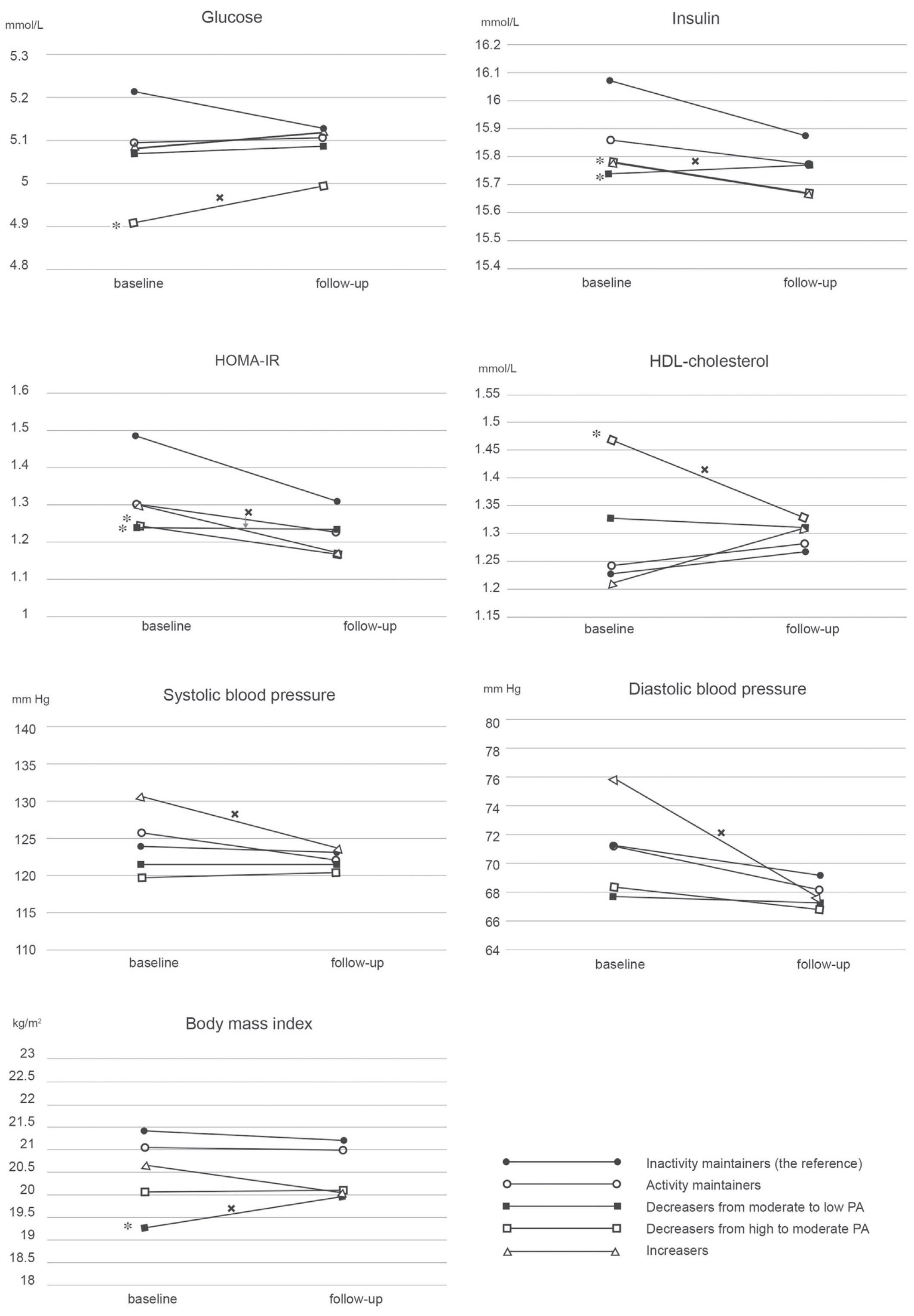

FIGURE 3 Development over time of cardiometabolic risk factors across longitudinal physical activity patterns. Development over time of cardiometabolic risk factors across longitudinal physical activity patterns among non-smoking/non-snuff-using men with no fruit/vegetable consumption. Estimated using the parameters of the linear growth curve models after adjusting for the change in the device wear-time. The symbol * represents a statistically significant difference in the baseline level (intercept). The symbol × represents a statistically significant change over time (slope) as compared to the reference (inactivity maintainers). HDL, high-density lipoprotein; HOMA-IR, homeostasis model assessment for insulin resistance; PA, physical activity.

cardiometabolic health concerns in the population exhibiting a decreasing PA. This was expected given that the study sample consisted for the most part of relatively active young people. The results do, however, demonstrate PA effects on cardiometabolic health from adolescence to early adulthood (findings that are independent of sex, fruit and vegetable consumption, or cigarette/snuff use). One should also take into account the baseline level of the outcome. For example, among *decreasers from high to moderate PA* the levels of HDL cholesterol, and glucose were more favorable at baseline than those of the reference group. Hence, the unfavorable changes in these risk factors did not result in particularly poor follow-up results.

The transition to young adulthood is one of the most fundamental periods of life in terms of PA-related behavior, given that PA may be influenced by e.g. moving out of the childhood family, cohabiting, starting further studies or entering working life.[35,36] During a 30-year follow-up[37] it was found that a low level of MVPA among young adults was associated with increased odds of diabetes, a higher level of triglycerides, and a lower level of HDL cholesterol in later life. The present study adds to this, indicating that the *risk* for cardiometabolic diseases is not just something that will occur far in the future, insofar as changes in PA were associated with changes in cardiometabolic risk already at adolescence.

An increase in BMI is generally a sign of increased cardiometabolic risk; however, during adolescence the increase is not necessarily an unfavorable result, since it may arise from an increase in lean body mass. Moreover, during adolescence, the increase in BMI might also be a result of normal body development and maturation. This might be the case among *decreasers from moderate to low PA*, bearing in mind that the BMI was lower at baseline as compared to the *inactivity maintainers*. On the other hand, no statistical difference was found between the participants according to the stage of puberty they had reached (Table 1).

The decrease in blood pressure among *increasers*—who were physically active already at baseline—is logical. However, due to the small number of persons exhibiting this PA pattern, the finding needs confirmation from further studies with a larger study sample. The small number of *increasers* may also be one explanation for the lack of other significant differences in cardiometabolic risk factors at baseline or over time in this PA pattern.

It is somewhat surprising that there was no statistically significant difference in any of the studied cardiometabolic risk factors between the *activity maintainers* and the *inactivity maintainers*, although the baseline values of insulin and HOMA-IR were very close to significance (Table S2). One could have expected that the baseline or follow-up levels of the risk factors would show a benefit from the maintenance of relatively high PA, but this was not indicated in the study. One explanation might be that the reference group was not extremely inactive (with mean MVPA 47 min/day at age 15), even if it was below the PA recommendation for children and adolescents, that is, at least 60 min/day of MVPA.[38] The population in the present study represented young people who were more active than the average in Finland, with the mean daily MVPA being 8 min more than that found in a previous population-based study.[10,39] Furthermore, 39% of the participants in the present study were still participating in sports club as young adults. The result demonstrates that the consequences of both decreased and increased PA can be seen even when the reference group is that of young people who maintain a relatively low—but not extremely low—level of activity from adolescence to young adulthood. This can be considered an important and new finding.

4.1 | Comparisons with other studies and perspectives for future research

A few previous studies on objectively measured PA during youth have examined cardiometabolic health outcomes between distinct data-based PA patterns[15,17]; however, no studies have so far examined the associations of PA patterns with blood biomarkers. Moreover, the self-reporting of PA,[14] or the lack of a data-driven method for grouping PA patterns[16]—or both[13,18]—have lessened comparability to the present study. Nevertheless, our finding indicating an increase in BMI among *decreasers from moderate to low PA* is consistent with previous studies showing increased accumulation of body adiposity[17] and obesity development[15] among groups displaying decreasing activity.

It should be noted that little attention has so far been paid to *changes* in health indicators. Overall, it has been more common to examine the level of the health outcome at follow-up, for example in young adults.[13,14,17] Undoubtedly, comparisons at follow-up are useful; however, going beyond these, examination of the change in health indicators over time—via a valid methodology for prospective research—can broaden knowledge of the phenomena in question. Growth curve modeling (growth mixture modeling), latent profile analysis, and related approaches (as used in this article) have been recommended also by other researchers in efforts to gain a better understanding of the nuances in young people's health.[40] Mention has also been made of the need for studies on health outcomes beyond adiposity (e.g. using blood biomarkers[5]).

An interesting perspective for future research would be analysis of the healthy thresholds of PA, that is, how much PA is needed to maintain cardiometabolic health benefits during the transition to young adulthood. In one study, 88 min of daily MVPA was concluded to be necessary to prevent clustering of risk factors in 15-year-old adolescents.[41] A further research gap has been mentioned regarding PA guidelines, which have been criticized changing too rapidly as adolescents turn into 18-year-olds.[6] In fact, the same PA guidelines are still issued for young adults and for older people approaching retirement age, in the absence of any proper research evidence from young adults. Another unsolved question is how much of a *change in PA* is needed to modify the cardiometabolic status of growing adolescents.

4.2 | Strengths and limitations

The main strengths of this study are the use of prospective and diverse data on cardiometabolic risk factors from a less-studied period of life (see also Ref.[5,6,11]), data-driven determination of longitudinal PA patterns measured via accelerometry, and the research methodology that enabled analysis of changes in cardiometabolic outcomes over time. Furthermore, adjustment by other health behaviors increased the quality of this study.

However, the results of this study should be interpreted with caution for several reasons. Females and adolescents with higher school achievement were over-represented in the study sample, and it encompassed only two measurement points. The number of persons in some of the PA patterns was small, which decreased the statistical power. On the other hand, the recruitment of participants from six different regions of Finland (from 100 schools and 156 sports clubs) increased the quality of this study, even if the results are not directly generalizable to the entire Finnish age cohort in question. The study sample was also somewhat more active than would be found among Finnish young people on average – although this was also a strength, insofar as the data also allowed analysis of PA changes from high baseline levels. While accelerometry is the state-of-the-art method to assess PA via a device,[42] one should bear in mind the related challenges; for example, the 7-day measurement period might not be representative of the habitual behavior of every participant. Moreover, use of the device tends to underestimate the vigorous PA occurring in certain types of PA, such as skating and weight training (see also Ref.[21])—even though moderate and vigorous PA were combined in our analyses.

5 | PERSPECTIVES

The study provided new evidence on how different longitudinal PA patterns are associated with changes in cardiometabolic risk factors already during adolescence and young adulthood (between ages 15 and 19). A favorable (decreasing) trend emerged in the systolic and diastolic blood pressure of adolescents whose PA increased over time, as compared to those who maintained a relatively low level of PA. Correspondingly, unfavorable changes in insulin and BMI occurred among *decreasers from moderate to low PA*, and in glucose and HDL cholesterol among *decreasers from high to moderate PA*. Hence, it seems that different changes in cardiometabolic risk factors may be expected in relation to differing baseline PA levels and the magnitude of the change in PA. Cardiometabolic risk factors are known to change during adolescence and sufficiency of MVPA may influence the changes in these risk factors. One can therefore suggest that the promotion of PA may be highly beneficial to individuals in this age-bracket, especially for those with greater cardiometabolic risk.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no competing interests.

DATA AVAILABILITY STATEMENT

The datasets generated and/or analyzed during the current study are not publicly available, since they contain confidential personal details and health information; however, they are available from the corresponding author on reasonable request.

ORCID

Tuula Aira https://orcid.org/0000-0001-9770-1732
Sami Petteri Kokko https://orcid.org/0000-0001-9436-5681
Olli Juhani Heinonen https://orcid.org/0000-0002-1722-1729
Raija Korpelainen https://orcid.org/0000-0002-3627-0542

Jari Parkkari https://orcid.org/0000-0001-5211-9845
Kai Savonen https://orcid.org/0000-0002-6871-8153
Maarit Valtonen https://orcid.org/0000-0001-8883-2255
Henri Vähä-Ypyä https://orcid.org/0000-0001-7537-2501
Tommi Vasankari https://orcid.org/0000-0001-7209-9351

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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