JYU DISSERTATIONS 475

Laura Joensuu

Longitudinal Study on Physical Fitness Characteristics in Adolescents with Special Reference to the Determinants of Change and Associations with Perceived Health

UNIVERSITY OF JYVÄSKYLÄ
FACULTY OF SPORT AND
HEALTH SCIENCES

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ABSTRACT

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This study entity evaluated how body composition, physical activity (PA) and maturity are associated with physical fitness (PF) status and development during adolescence. We furthermore examined PF development on an individual level and in adolescents with impaired PF. Additionally, we estimated longitudinal associations between PF and self-rated health (SRH). This study entity was designed to provide novel information related to the Finnish national Move! − monitoring system for physical functional capacity and to help interpret the results at the practical level.

Data from a 2-year longitudinal observational study were used (2013–2015, n = 970, 12.6 ± 1.3 years, 52.4% girls). Participants completed annual assessments of PF (Move! measurements: cardiorespiratory fitness (20-m shuttle run), muscular fitness (push-up, curl-up), fundamental movement skills (throwing-catching combination test, 5-leaps jump), and flexibility (squat, lower back extension, shoulder stretch)), body composition (bioimpedance), maturity status (Tanner scale), PA (accelerometer, self-reported) and SRH.

The main findings reveal that PF develops naturally during adolescence, but that both PF status and development are systematically with practical relevance attenuated by excess adiposity. Low PF tends to be sustained during adolescence in a group and at an individual level. PF is cross-sectionally associated with SRH but does not explain SRH at the 2-year follow-up.

In conclusion, PF measured with weight-bearing assessments reflects an individual's ability to perform physically demanding tasks. PF attainment can be supported by healthy weight gain during growth and maturation. PF does not explain future SRH in this study sample, but PA does, and most coherent favourable associations are observed with self-rated PA. It is therefore important to evaluate which variables are the best predictors for health outcomes in specific populations.

Keywords: functional capacity, performance, youth, children, physical fitness monitoring

TIIVISTELMÄ (ABSTRACT IN FINNISH)

Joensuu, Laura
Nuorten fyysiset kunto-ominaisuudet – muutosta selittävät tekijät ja yhteydet koettuun terveyteen
Jyväskylä: Jyväskylän yliopisto, 2021, 94 s. + alkuperäiset artikkelit
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Tässä tutkimuskokonaisuudessa selvitettiin, kuinka kehonkoostumus, fyysinen aktiivisuus ja murrosiän vaihe ovat yhteydessä fyysiseen kuntoon ja kunnon kehittymiseen nuorilla. Fyysisen kunnon kehittymistä tutkittiin yksilötasolla sekä niillä, joiden fyysinen kunto on alentunut. Tutkimuksessa arvioitiin myös fyysisen kunnon ja koetun terveyden välisiä pitkittäisyhteyksiä. Tutkimuskokonaisuuden tavoitteena oli tuottaa uutta tutkimustietoa Move! – fyysisen toimintakyvyn seurantajärjestelmästä.

Aineistona käytetiin Oppilaiden liikunta ja hyvinvointi -seurantatutkimusta vuosilta 2013–2015. Tutkimukseen osallistui 970 nuorta (12,6 ± 1,3 vuotta, 52,4 % tyttöjä), jotka toteuttivat vuosittain fyysisen kunnon, kehonkoostumuksen, murrosiän vaiheen, liikunta-aktiivisuuden ja koetun terveyden mittaukset. Fyysisen toimintakyvyn Move!-mittauksilla arvioitiin kestävyyskuntoa (20 metrin viivajuoksu), lihaskuntoa (etunojapunnerrus, ylävartalon kohotus), motorisia perustaitoja (heitto-kiinniottoyhdistelmä, vauhditon 5-loikka) ja kehon liikkuvuutta (kyykistys, alaselän ojennus täysistunnassa, olkapäiden liikkuvuus oikea ja vasen käsi ylhäällä). Kehonkoostumusta arvioitiin bioimpedanssimenetelmällä, murrosiän vaihetta kyselyllä Tannerin asteikon avulla, fyysistä aktiivisuutta kiihtyvyysanturilla ja kyselyllä sekä koettua terveyttä kyselyllä.

Tutkimuksen päätuloksena oli, että fyysiset kunto-ominaisuudet kehittyvät luonnollisesti murrosiän aikana, mutta liiallinen kehon rasvakudoksen määrä vaimentaa sekä kuntotasoa että kunnon kehittymistä. Alentuneen kuntotason havaittiin säilyvän murrosiän aikana sekä ryhmä- että yksilötasolla. Fyysinen kunto oli poikkileikkausasetelmassa yhteydessä koettuun terveyteen, mutta ei ennustanut tulevaa koettua terveyttä kahden vuoden seurannassa.

Tutkimuksen johtopäätöksinä ovat, että kehonpainoa vasten tehtävät fyysisen kunnon mittaukset kuvastavat henkilön kyvykkyyttä toteuttaa fyysisiä tehtäviä. Terveellinen painokehitys kasvun, kypsymisen ja kehityksen aikana tukee fyysisen kunnon kehittymistä. Fyysinen kunto ei tässä tutkimusjoukossa selittänyt tulevaa koettua terveyttä, mutta itseraportoitu liikunta-aktiivisuus selitti. Onkin tärkeää arvioida, mitkä muuttujat selittävät parhaiten terveyttä eri väestöryhmissä.

Asiasanat: fyysinen toimintakyky, fyysinen kunto, kouluikäiset, murrosikä, Move! – fyysisen toimintakyvyn seurantajärjestelmä

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My journey with this thesis started in 2013 with data collection. A new phase unfolded in 2016 with the onset of my own research. At that time, I was not quite sure to which I had agreed, but it quickly felt like I had to abandon my former role and start to find my way through the suddenly emerged unclarity and uncertainty within science.

I have come across many people during this journey, to whom I want to express my gratitude. I have had the privilege of working in an inspiring research community. I remember the time I attended my first international scientific congress, the Paediatric Work Physiology (PWP) in Greece. I presented my very first and yet preliminary findings to a room full of experts in this field. After the presentation, the Chair asked me what is the 'So What?' of my findings. I remember to struggle a bit to answer and finally said, 'I hope I am going to eventually find that out assisted by you all.' And now, when it is time to write these last sentences to my thesis, I can truly say that is exactly what has happened.

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Jyväskylä 13.6.2021
Laura

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A researcher's wish

Dear adolescent

On your journey,
from childhood,
to adulthood

I wish you
all the best,
and the possibility

To grow
To be able
To be whole

—Laura Joensuu

LIST OF ORIGINAL PUBLICATIONS

This dissertation is based on the following original peer-reviewed scientific publications. The articles are referred to in the text by their Roman numerals.

I Joensuu, L., Syväoja, H., Kallio, J., Kulmala, J., Kujala, UM. & Tammelin TH. 2018. Objectively measured physical activity, body composition and physical fitness: Cross-sectional associations in 9- to 15-year-old children. European Journal of Sport Science, 18 (6), 882-892. doi: 10.1080/17461391.2018.1457081.

II Joensuu, L., Kujala, UM., Kankaanpää, A., Syväoja, HJ., Kulmala, J., Hakonen, H., Oksanen, H., Kallio, J. & Tammelin, TH. 2021. Physical fitness development in relation to changes in body composition and physical activity in adolescence. Scandinavian Journal of Medicine & Science in Sports, 31 (2), 456-464. doi: 10.1111/sms.13847.

III Joensuu, L., Rautiainen, I., Äyrämö, S., Syväoja, HJ., Kauppi, J-P., Kujala, UM. & Tammelin TH. 2021. Precision exercise medicine: predicting unfavorable status and development in the 20-m shuttle run test performance in adolescence with machine learning. BMJ Open Sport & Exercise Medicine, 7, e001053. doi: 10.1136/bmjsem-2021-001053.

IV Joensuu, L., Tammelin, TH., Syväoja HJ., Barker, AR., Parkkari, J. & Kujala UM. Physical activity, physical fitness, and self-rated health: Cross-sectional and longitudinal associations in adolescent. Submitted.

The Doctoral Candidate Joensuu contributed to planning the doctoral research entity, coordinating and conducting the measurements, analysing and/or interpreting the data, drafting and reporting the work, and revising critically the intellectual content in all studies. In Study III, Mr. Ilkka Rautiainen contributed equally to the work. In Study III, Rautiainen planned and conducted the data analyses, and Joensuu handled the study design.

FIGURES

TABLES

ABBREVIATIONS

BMI	Body mass index
CRF	Cardiorespiratory fitness
FFM	Fat-free mass
FFMI	Fat-free mass index
FM	Fat mass
FMI	Fat mass index
FMS	Fundamental movement skills
MF	Muscular fitness
MVPA	Moderate-to-vigorous physical activity
PA	Physical activity
PF	Physical fitness
ST	Sedentary time
VO_2 max	Maximal oxygen consumption
WHO	World Health Organisation

CONTENTS

1 INTRODUCTION

Evaluating adolescents' physical fitness has a long history. Fitness testing within physical education began in 1861 at Amherst College in the USA with anthropometric documentation by Edward Hitchcock. The origins of the current form of fitness testing in schools extend to the 1960s and the USA, where first fitness testing batteries were developed after scientific revelations that American schoolchildren were less fit than their European counterparts (Kemper & Van Mechelen 1996). The first fitness testing battery was called the Youth Fitness Test and was developed by the American Association for Health, Physical Education, and Recreation (U.S. Department of Health and Human Services 1996, 17). Since then, various methods to monitor physical fitness in school-aged children have been developed.

When writing this thesis, there are at least seven European countries with national-level monitoring systems for physical fitness in school-aged children. Systems operate in Slovenia (since 1982), France (2010), Hungary (2015), Finland (2016), Portugal (2016), Serbia (2017) and Lithuania (2020) (The European Network for the Support of Development of Systems for Monitoring Physical Fitness of Children and Adolescents 2021) Notable is the increase in national monitoring systems during the past five-to-six years. This increase reflects the growing motivation to assess physical fitness in school-aged children in Europe.

In Finland, fitness measurements have been conducted regularly in schools during the past decades, with research and development with the early version of the EUROFIT testing battery extending to the 1970s (Nupponen et al. 1979). In 2016, a revised national monitoring system was launched, called the Move! − monitoring system for physical functional capacity, alongside the curriculum reform within basic education (Finnish National Agency for Education 2021). The Move! system was developed by the Faculty of Sport and Health Sciences at the University of Jyväskylä affiliated with the Ministry of Social Affairs and Health, the National Institute for Health and Welfare and the Trade Union of Education in Finland, and is managed by the Finnish National Agency for Education and Ministry of Education and Culture. The main purpose of the system is to act as an educational tool and to encourage students to independently take care of their physical functional capacity. In this monitoring system, the physical fitness of every 5th and 8th grade (approximately 11 and 14 years old) schoolchild is annually assessed during the school day and addressed later individually in the student's health examinations. The measurements include a 20-metre shuttle run test (measurement of cardiorespiratory fitness), push-up and curl-up (muscular fitness), squat, lower back extension in sitting posture and shoulder stretch (flexibility), 5-leaps test and throwing-catching combination test (fundamental movement skills). A national database is collected, and feedback is provided at the national, regional, local and school levels to inform policymakers. During Fall 2020, a total of 53,502 5th and 51,397 8th grade students participated in the measurements, equivalent to > 90% of the population (Finnish National Agency for Education 2021).

Physical fitness monitoring can be used to educate students and advance their physically active lifestyles via growing physical literacy. Physical literacy can be defined as '… motivation, confidence, physical competence, understanding and knowledge to maintain physical activity at an individually appropriate level, throughout life' (Whitehead 2001). Fitness measurements have also reportedly direct associations with health-related risk factors (Lang et al. 2018) and are recommended to be used as a tool to identify individuals at risk of developing chronic illnesses. Additionally, the national data can be utilised in policymaking. The recent COVID-19 pandemic has shown the value of monitoring, as the only such effects of the pandemic can be assessed where data exists. Interestingly, the 2020 Move! measurements showed that the overall trends in physical fitness remain surprisingly unaffected over the first half-year of exceptional circumstances in children and adolescents in Finland (Finnish National Agency for Education 2021). Comparison with other countries is difficult, as data is rare. The first findings from Slovenia, however, show worryingly that only two months of confinement substantially decreased the physical fitness status of children and adolescents and eroded the population-level development gained during the past 10 years (Jurak et al. 2021).

Therefore, one could argue that there is a solid rationale for promoting physical fitness monitoring in children and adolescents. However, physical fitness monitoring has remained a polemic topic throughout the decades. Since the early implementation of the first fitness testing batteries, differences in philosophy and aims have induced a confusing number of available testing batteries (Kemper & Van Mechelen 1996). A recent systematic review identified 25 different field-based health-related fitness test batteries aimed at children and adolescents, comprising 87 separate fitness assessments (Marques et al. 2021). During recent decades, the health-related associations of physical fitness have emerged as the most utilised rationale for fitness testing, derived from the association between laboratory-measured physical fitness and health indicators (Blair 2009). Strong critique has been addressed towards this approach, and field-based measurements have been argued to be invalid representatives of laboratory-measured physiological attributes of physical fitness (Armstrong & Welsman 2019). Additionally, fitness measurement is suggested to be replaced with other measurements with stronger associations with health than physical fitness, e.g. physical activity assessment (Rowland 1995). Furthermore, concerns are addressed that fitness testing is demeaning or embarrassing for those participants in the main target group, i.e. the children and adolescents with the lowest physical fitness (Rowland 1995).

The basis of physical fitness monitoring systems is the systematic ongoing research needed to resolve various challenges (Safrit 1990). This study entity takes part in the ongoing academic conversation related to monitoring physical fitness in adolescents. This study provides among the first scientific entities novel information on how to interpret the measurements included in the Move! system. This study explains how the Move! results change during adolescence, what factors are associated with the results and their change, and how Move! results explain future overall indicators of health, i.e. self-rated health.

This study provides meaningful information for the practitioners involved in the Move! system and for those utilising international field-based physical fitness monitoring systems. This study provides insights into and elucidates why fitness development during adolescence is a unique phase of life and how physical fitness attainment could be supported during adolescence.

2 REVIEW OF THE LITERATURE

2.1 Adolescence

adolescere

(verb)
to grow up

2.1.1 Definition of adolescence

The word adolescence derives originally from the Latin word adolescere with an English translation 'to grow up' (Hoad 2003; Sawyer et al. 2018). Adolescence is a unique phase of life when a child progresses from childhood to adulthood. During adolescence, a child undergoes a complex transitional process, including elements of growth, maturation and development, with all these processes occurring concurrently, although separately, and proceeding with an individual timing and tempo (Malina 2014). Timing refers to the establishment of specific milestones, while tempo refers to the rate of change (Malina 2014; Sawyer et al. 2018).

Growth is defined as an 'increase in size of the body as a whole and of its parts' referring to changes in body height and mass, and alterations in body proportions with growth in different body segments (Malina 2014). Maturation is defined as 'progress towards the biologically mature state or biological maturity.' Maturation refers to the process, whereas maturity is a state. Maturation occurs in all bodily organs and systems, but maturity varies with specific biological systems, e.g. sexual maturity refers to the ability to reproduce, and skeletal maturity to a fully ossified skeleton (Malina 2014). Development in this context refers to the 'acquisition and refinement of behaviours expected and in many instances set by society', e.g. development in cognitive, social, affective, moral and other behaviours (Malina 2014).

These processes are present in the daily lives of children and adolescents during the first two decades of the life span (Malina 2014). The World Health Organisation (WHO) has proposed that the age range of adolescence spans from 10 to 20 years of age (World Health Organization 1977). It has been recognised that the defining exact period for adolescence is problematic as the physiological and psychosocial milestones are established at different rates in different individuals and in different societies (World Health Organization 1977).

Most cultures relate adolescence to commence with puberty, i.e. changes in the hormonal profile manifested as growth spurt and secondary sex characteristics (Sawyer et al. 2018). However, the endpoint of adolescence, i.e. time when adulthood begins and adult roles, prerogatives and responsibilities are met, differs between societies (World Health Organization 1977). The concept of adolescence is under change, as the advanced onset of puberty has accelerated adolescence in most societies, while the endpoint has typically been lifted due to later adoption of roles related to adulthood, e.g. marriage, parenthood and completion of education (Sawyer et al. 2018). Therefore, recently, a proposal has been made to expand the age range of adolescence from 10 to 20 years old to 10 to 25 years old (Figure 1).

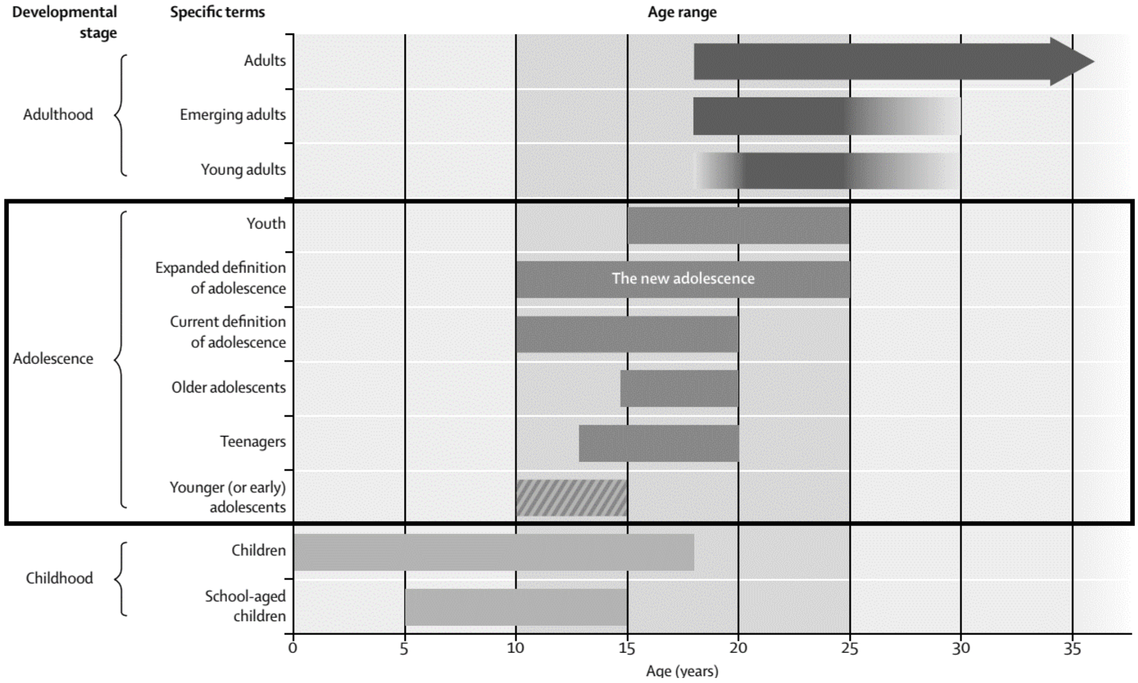

FIGURE 1. Commonly used age ranges for childhood, adolescence and adulthood. Modified with permission from Sawyer et al. 2018

2.1.2 Assessments of growth, maturation and development

The markers of growth, development and maturation are often in the core interest of exercise scientists working with adolescents. Chronological age is a basic reference in studies with adolescents. Typically, decimal age is used, which is calculated from the date of birth to the date of measurement, e.g. 9.47 years. Although indicators of growth, maturation and development typically change alongside age, chronological age cannot fully explain the complex procedures in these variables. If these variables are not recorded, e.g. in an experiment, concluding whether changes observed were an effect of the experiment or due to normal growth, maturation and development will be difficult (Baxter-Jones 2017; Malina 2017).

Height and weight are primary indicators of growth and are comparable with growth charts that comprise normal ranges and standard deviations. Stature—standing height—is standardly measured with a stadiometer in a standing position from the standing surface to the top of the skull (vertex). Weight is a simple measure of overall body mass (Malina 2017). Body mass is often partitioned into elements of body composition, i.e., fat-free mass (FFM), and fat mass (FM). Two major components of fat-free mass are lean tissue mass and bone mineral content. Dual energy X-ray absorptiometry and bioelectrical impedance analyses are often used to assess body composition in adolescent populations. The body mass index (BMI) is commonly used to evaluate weight relative to body surface area (weight (kg)/height (m^2)) and degree of obesity (Malina 2017).

Assessments of maturity most often include skeletal and/or pubertal maturation. The three most commonly used methods to estimate skeletal age are described in detail elsewhere (Malina 2017). Secondary sex characteristics are commonly used to assess the maturity status with the five stages developed by Tanner (1962). The stages include evaluating pubic hair and penis, scrotum and testes or breasts. First stage includes prepubertal participants without indications of maturation in secondary sex characteristics. The Stages 2, 3 and 4 represent different stages in maturity, and Stage 5 indicates the fully mature state (Malina 2017). Also, other assessments can be utilised to assess maturity, which is beyond the scope of this thesis. These include, in girls, the menarcheal status (pre or post) and chronological age at menarche, and age at peak height velocity, i.e. when growth velocity in height is accelerated to its maximum during adolescence (Malina 2017).

One key element of development in adolescents—the change in behaviour— is physical activity. Physical activity is defined as 'any bodily movement produced by skeleton muscles that results in energy expenditure' (Caspersen et al. 1985). Physical activity can be further classified based on its domain into, e.g. occupational, household or leisure-time. Exercise is a subset of physical activity referring to a planned, structured and repetitive action that has the objective of improving or maintaining physical fitness (Caspersen et al. 1985). Physical activity can be measured using questionnaires (e.g. Health Behaviour in School-Aged Children (HBSC)) or with devices. With devices, e.g., accelerometers, metrics of standardly collected intensity and duration of physical activity can be achieved, including sedentary behaviour and sleep duration in 24-h measurements. Device-based physical activity measurements, however, have their limitations. Accelerometers do not capture all activity (such as cycling) or separate the type of activity (whether it is enhancing, e.g. muscle strength or motor skills) (Strath et al. 2013).

2.1.3 Regulation of adolescent growth, maturation and development

Growth and maturation involve complex and continuous interaction of genes, hormones, nutrients and the environment. The genotype has the biological potential for growth and maturation; however, environmental and behavioural factors are associated with the observed physical traits (Baxter-Jones 2017). Adolescents experience a growth spurt in stature and weight. Girls reach the peak height velocity on average at 12 and boys at 14-year old. Approximately 0.3–0.9 years after peak height velocity in girls and 0.2–0.4 years in boys, there is a rapid gain in body mass. Girls show increased muscle mass, but to a lesser degree than boys, and a continuous rise in fat mass during adolescence. Boys mainly increase muscle mass, while fat mass remains relatively stable (Baxter-Jones 2017).

Puberty is ignited and regulated by the reactivation of the hypothalamus, pituitary gland and gonad axis (HPG axis) during adolescence (Abreu & Kaiser 2016). The increased activity of the HPG axis leads to increases in oestradiol levels in girls and testosterone levels in boys. These elevated levels of oestrogens and androgens result in the acceleration of growth, manifestation of secondary sex characteristics and changes in body mass and composition (Baxter-Jones 2017).

Behaviour changes during adolescence, and an observable decrease in physical activity occurs with age. Many longitudinal studies have verified this phenomenon (Figure 2 as an example). Evidence has shown that physical activity is biologically regulated, and the decline in activity levels is related to the lesser stimulus required to support the developmental processes of the body when approaching full maturation (Rowland 1998).

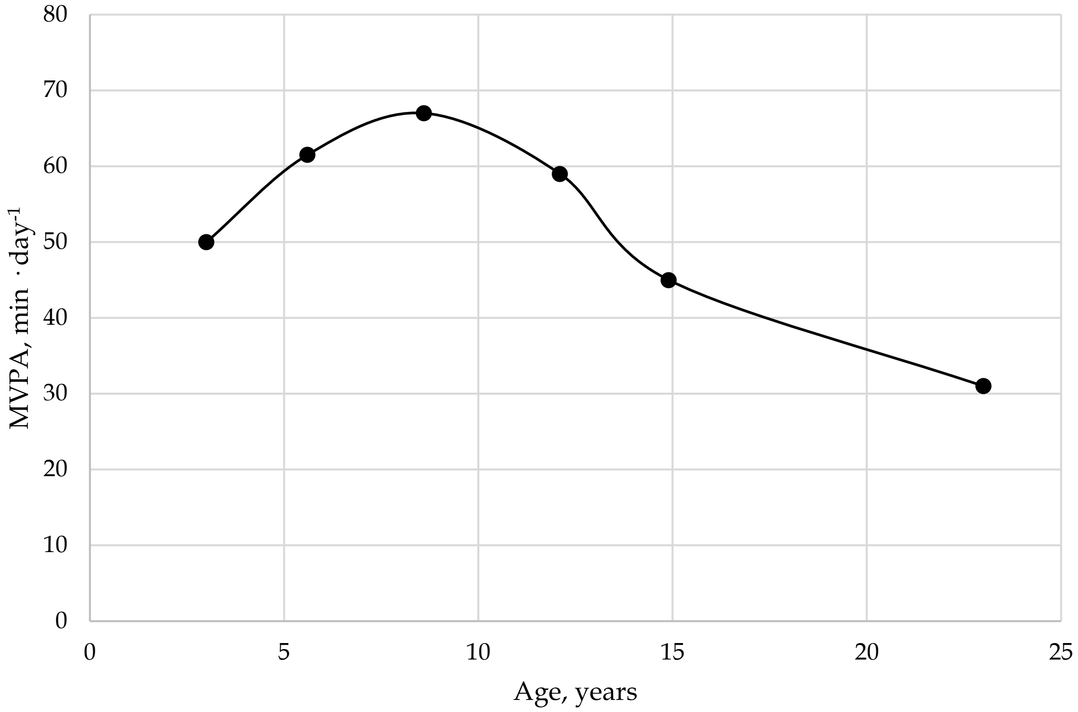

FIGURE 2. Accelerometer-based moderate-to-vigorous physical activity (MVPA) in Finnish children, adolescents and young adults. Reproduced with permission (Kämppi & Tammelin 2018, 12)

2.2 Physical fitness in adolescents

fit +ness

(noun)

the condition of being fit, suitable or appropriate.

2.2.1 Definitions of physical fitness

Although physical fitness has been assessed in some form throughout the centuries, no single definition for it and its characteristics have been established. The foundations of physical fitness terminology were formed in 1936 when Arthur Steinhaus published one of the earliest articles, including the term 'physical fitness', in the Journal of Health, Physical Education, and Recreation (U.S. Department of Health and Human Services 1996). Physical fitness has been evaluated with different aims and perspectives, and the definitions have evolved and expanded to fit these specific purposes.

One of the key papers defining the modern concept of physical fitness was published by Caspersen, Powell and Christenson (1985). In their original paper, the authors provided few definitions for physical fitness. Being physically fit refers to 'the ability to carry out daily tasks with vigour and alertness, without undue fatigue and with ample energy to enjoy leisure-time pursuits and to meet unforeseen emergencies', originally formed by President's Council on Physical Fitness and Sports in 1971 (Caspersen et al. 1985). Furthermore, physical fitness 'is a set of attributes that people have or achieve', including cardiorespiratory endurance, muscular endurance, muscular strength, muscular power, speed, flexibility, agility, balance, reaction time and body composition, which relate to the ability to perform physical activity. Because these attributes originally have been perceived to differ in their importance between athletic performance and health, physical fitness was further defined as either health- or skill-related fitness (Table 1) (Caspersen et al. 1985; U.S. Department of Health and Human Services 1996). However, the growing body of knowledge challenges the meaningfulness of this separation. Skill-related fitness reportedly develops simultaneously with cognitive skills and is therefore important for brain health and function (Diamond 2000; Davis et al. 2011). And on the other hand, muscular strength and cardiorespiratory fitness are important factors in athletic performance (Faigenbaum & Rhrodri 2017; Tolfrey & Smallcombe 2017).

TABLE 1. Classical definitions of physical fitness and its attributes by Caspersen, Powell and Christenson (1985).

Physical fitness *'a set of attributes that people have or achieve that relates to the ability to perform physical activity'*	
Skill-related fitness	**Heath-related fitness**
Agility *'…the ability to rapidly change the position of the entire body in space with speed and accuracy'*	Cardio-respiratory endurance *'…the ability of the circulatory and respiratory systems to supply fuel during sustained physical activity and to eliminate fatigue products after supplying fuel'*
Balance *'…the maintenance of equilibrium while stationary or moving'*	Muscular endurance *'…the ability of muscle groups to exert external force for many repetitions or successive exertions'*
Coordination *'…the ability to use senses, such as sight and hearing, together with body parts in performing motor tasks smoothly and accurately'*	Muscular strength *'…the amount of external force that a muscle can exert'*
Speed *'…the ability to perform a movement within a short period of time'*	Body composition *'…the relative amounts of muscle, fat, bone, and other vital parts of the body'*
Power *'…the rate at which one can perform work"*	Flexibility *'…the range of motion available at a joint'*
Reaction time *'…the time elapsed between stimulation and the beginning of the reaction to it'*	

In a position paper by the American College of Sports Medicine, this classical definition is recognised, but for practical purposes, they are categorized more broadly by main operational anatomical domains as cardiorespiratory, musculoskeletal and neuromotor fitness (Garber et al. 2011). This thesis utilises definitions based on this American College of Sports Medicine categorisation, which also best complement the testing battery included in the Move! system (Table 2).

TABLE 2. Selected physical fitness test batteries for children and adolescents.

Age range	Published	Name	Physical fitness characteristics: *related measurements*
11 and 14	2016	Move! – monitoring system for physical functional capacity	Cardiorespiratory fitness: *20-m shuttle run* Muscular fitness: *Curl-up, Push-up* Flexibility: *Squat, Lower back extension in sitting posture, Shoulder stretch* Fundamental movement skills: *5-leaps jump, Throwing-catching combination test*
6–18	2009	ALPHA health-related fitness test battery	Cardiorespiratory fitness: *20-m shuttle run* Muscular fitness: *Handgrip strength, Standing broad jump* Body composition: *Body mass index, Waist circumference, Skinfold measurement*
6–18	1988	EUROFIT	Cardiorespiratory fitness: *20-m shuttle run* Muscular fitness: *Standing broad jump, Sit-ups, Handgrip strength, Bent arm hang* Flexibility: *Sit-and-reach* Balance: *Flamingo balance* Speed: *Plate tapping* Agility: *10 × 5-m shuttle run*
5–17	1987	FitnessGram	Cardiorespiratory fitness: *20-m shuttle run OR 1-mile walk/run* Muscular fitness: *Curl-up, Trunk lift, Push-up* Flexibility: *Back-saver sit-and-reach, Shoulder stretch* Body composition: *Body mass index, Skinfold measurement*

Cardiorespiratory endurance, cardiorespiratory fitness and aerobic fitness have been used as synonyms to describe with varying wording the 'body's integrated ability to deliver oxygen from the atmosphere to the skeletal muscles and to consume it to provide energy to support muscular activity during exercise' (Armstrong & McManus 2017; Welsman & Armstrong 2019). Muscular fitness incorporates both muscular strength and endurance. Flexibility refers to range of motion (Garber et al. 2011). A definition of musculoskeletal fitness encompasses both muscular fitness and flexibility (Plowman 2014).

In the neuromotor fitness domain, balance, agility and coordination are combined (Garber et al. 2011). Regarding this domain, important attributes for the adolescent population also include fundamental movement skills, that is, the 'building blocks of movement.' The mastery of fundamental movement skills is considered to contribute to children's physical, cognitive and social development and is thought to provide the foundation and an opportunity for an active lifestyle. These building blocks include locomotor (e.g. running and hopping), manipulative or object control (e.g. catching and throwing) and stability skills (e.g. balancing and twisting) (Lubans et al. 2010).

2.2.2 Assessing physical fitness

The degree of these attributes can be measured with specific tests (Caspersen et al. 1985). Tests are typically categorised into laboratory or field-based methods. Although laboratory measurements provide the highest evidence related to these attributes, there are still requirements to meet the varying motivations for PF monitoring in other circumstances. The motivation for physical fitness monitoring varies across countries and has evolved over time, but generally, it has clustered around military and occupational preparedness, obesity prevention, health promotion and surveillance and assessing the fitness status itself (Tomkinson et al. 2019).

To date, perhaps the most common testing batteries in the world are the FitnessGram, EUROFIT and, most recently, ALPHA health-related fitness test battery (Table 2). All these test batteries include a 20-m shuttle run as a marker of cardiorespiratory fitness, which is the most utilised field-based measurement in children and adolescents (Tomkinson et al. 2017). Muscular fitness, flexibility and neuromotor fitness domains include varying elements.

Field tests are considered feasible and reliable measures of physical fitness (Artero et al. 2011; Ruiz et al. 2011). However, they have their limitations. It is important to understand that although field tests are aimed to assess similar characteristics as laboratory measurements, more factors might contribute to the test results than in a laboratory setting. For example, muscular fitness can be measured in a laboratory in various ways: with different types of work (eccentric, isometric, isokinetic or dynamic), types of strength (maximal, explosive, endurance) and in different muscle groups. Field-based measurement can be performed with devices, e.g. with a dynamometer evaluating handgrip strength (maximal isometric strength of the forearm muscles), but mainly assessments are performed without devices with dynamic whole-body movements, e.g. muscle endurance with push-ups, curl-up or power with standing broad jump. Field-test results therefore comprise multiple factors, which in field settings are difficult to isolate/adjust from the result. Thus, acknowledging the different nature of field testing compared to laboratory measurements is imperative. Without acknowledging this distinction, confusion in the interpretation of fitness development during adolescence might occur (De Ste Croix 2017). Fitness status and development are specific to the metric with which they are measured with. To acknowledge this phenomenon, we narrow our focus in this thesis to the field-based physical fitness assessments included in the Move! – monitoring system for physical functional capacity.

2.2.3 Physical fitness during adolescence

Adolescence is an important timeframe related to physical fitness, as characteristics tend to peak or attain the highest proportion of development during adolescence. Fitness characteristics slowly decline from adolescence to adult life and older age. An example of a theoretical muscular fitness trajectory during a human life course is presented in Figure 3 (Mithal et al. 2013). Fitness capacity attained during adolescence is therefore meaningful for later life and can alter the time when the life-limiting disability threshold is met (Mithal et al. 2013).

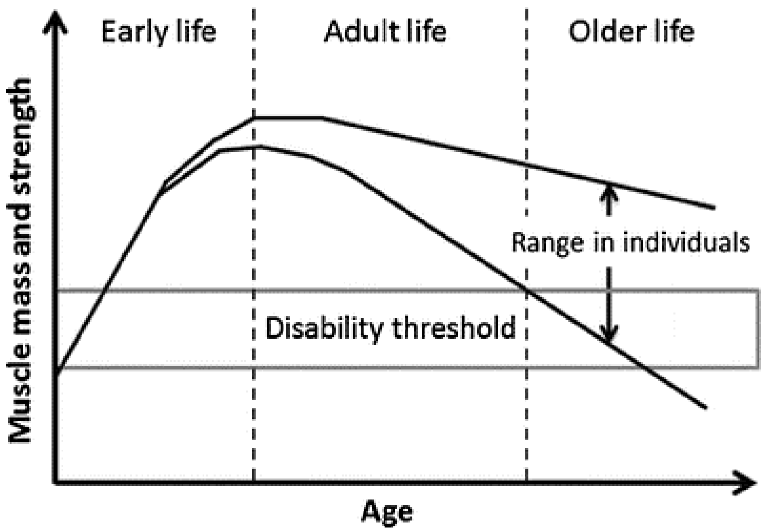

FIGURE 3. Trajectory for muscle mass and strength during the life course. Reproduced with permission from Mithal et al. (2013)

In theory, especially during adolescence, cardiorespiratory, muscular fitness and motor skills develop with age (Armstrong & MacManus 2017; De Ste Croix 2017; Sudgen & Soucie 2017). Cardiorespiratory fitness and muscle strength typically increase naturally alongside growth and maturation ignited morphological and neuromuscular changes (Armstrong & MacManus 2017; De Ste Croix 2017). Children typically gain fundamental gross motor skills by the age of seven and further hone these skills (Sudgen & Soucie 2017). Development in strength and endurance domains also improves performance in skill-related tasks, which require maximal performance (Sudgen & Soucie 2017). Flexibility is highly a location specific characteristic. Previous studies have found no association between adolescent growth or sexual maturation and markers of flexibility (Feldman et al. 1999; Kanbur et al. 2005).

Figures 4 and 5 show the development of physical fitness during adolescence assessed with the Move! system. The median values of age cohorts indicate that the performance scores increase from 4th Grade (approx. 10-year olds) to 9th Grade (approx. 15-year olds) in cardiorespiratory, muscular fitness and fundamental movement skills in both sexes. Flexibility shows varying results where some measurements remain stable, some fluctuate and some improve with age (Figures 4 and 5) (Finnish National Agency for Education 2021).

Some measurement protocols in the Move! system differ with age (curl-up, throwing-catching combination test) where the task is more difficult for older students, explaining the drop in performance scores between 6th and 7th Grades. Push-up and throwing-catching combination test protocols differ between sexes, where boys have a more difficult task, explaining why, for example, in push-up, boys' performance status is lower than in girls. Girls have lower performance during adolescence compared to boys in the 20-m shuttle run test, curl-up, and 5-leaps test, but girls have better overall flexibility (Figure 4 and 5) (Finnish National Agency for Education 2021).

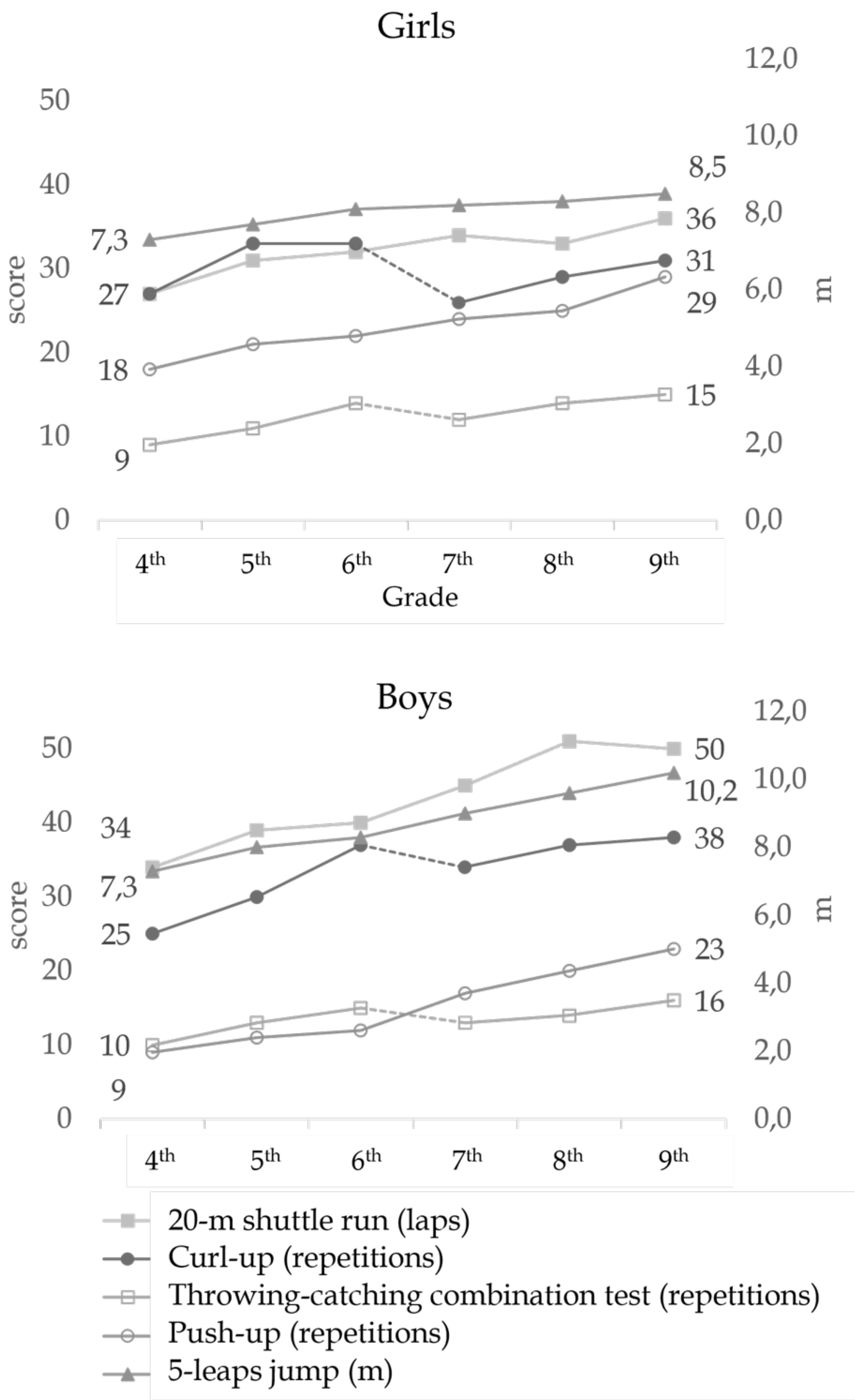

FIGURE 4. Median values for the assessments of cardiorespiratory, muscular fitness and fundamental movements skills included in the Move! system in a sample of Finnish adolescents

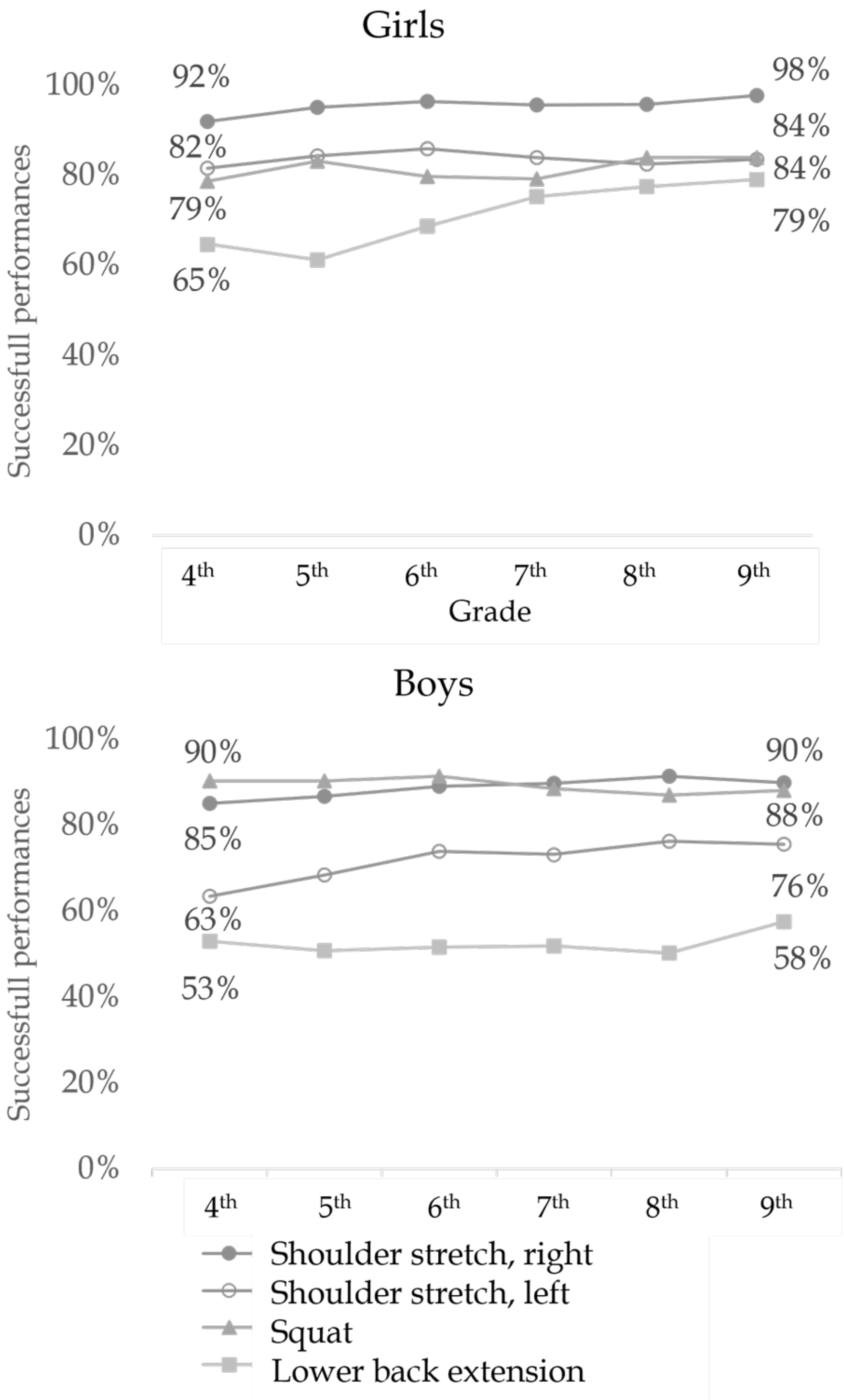

FIGURE 5. Success rate in the flexibility measurements included in the Move! system in a sample of Finnish adolescents

2.3 Health and adolescents

hælth

(noun)

whole, a thing that is complete in itself

2.3.1 Definition of health

The etymology of the English word 'health' refers to Old English *hælth*, which is related to a thing that is whole, complete in itself (Brüssow 2013). The World Health Organisation (WHO)'s 1948 definition of health is one of the key definitions of our time. The WHO defines 'health as a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity.' Although at the time of its establishment this definition was groundbreaking and overcame the negative connotations associated with health, it has been criticised over the decades (Huber et al. 2011). Main critique is addressed towards its aim for complete health, especially in an era where populations' age and prevalence of chronic diseases increase, and thresholds for interventions tend to be lowered (Huber et al. 2011).

2.3.2 Assessment of health and health risks in adolescents

One of the main strategies in exercise medicine is to prevent, treat and rehabilitate from diseases through exercise. Although all these aspects follow the adolescent population, the core focus of this thesis is addressed towards prevention. Mortality rate in Finnish children and adolescents is low in an international comparison with approximately 2 deaths/10 000 children. The main disease-related causes of death are chromosome and congenital abnormalities, tumours and diseases related to systemic biology, e.g. respiratory, neurological and endocrinological function (Statistics Finland 2018).

Typical indicators of health risks in adolescents include various precursors of diseases. Typical risk indicators for cardiometabolic diseases include blood lipids (elevated values in triglycerides, total cholesterol level and reduced high-density lipoprotein), elevated glucose levels, insulin levels, insulin resistance, inflammatory markers (C-reactive protein, homocysteine, interleukin-6) and blood pressure. Additionally, bone mineral content is a marker of risk for osteoporosis. Further description of different risk factors is beyond the scope of this summary.

In this study, we narrowed our focus to self-rated health. A simple self-rating of health on a scale from excellent to very poor is considered to give a powerful summary of an individual's overall health status (Fayers & Sprangers

2002). Self-rated health has resemblance to the WHO definition and the etymological basis of health, and it measures such a construct of health that is unachievable by clinical markers. In adolescents, a low rating of self-rated health is associated with low socio-economic status, unfavourable psychosomatic symptoms, smoking, alcohol consumption, physical inactivity, poor fitness and nutrition, and obesity (Vingilis et al. 2002; Tremblay et al. 2003; Piko 2007). Therefore, self-rated health in adolescents is considered an indicator of unhealthy behaviours and/or circumstances, even prior to the expression of chronic conditions (Piko & Keresztes 2007; Breidablik et al. 2008). As many as a third of adolescents report having some limitations in their self-rated health, with adolescent boys tending to report higher values compared to girls (Tremblay et al. 2003). Self-rated health has previously been shown to have good test–retest reliability (Lundberg & Manderbacka 1996), strong stability during growth and maturation (Boardman 2006), and tracking from adolescence to adulthood (Vie et al. 2014).

2.3.3 Physical fitness and self-rated health

Cross-sectional findings have shown low levels of cardiorespiratory fitness (Mota et al. 2012; Padilla-Moledo et al. 2012; Kantomaa et al. 2015), muscular fitness (Padilla-Moledo et al. 2012) and self-reported fitness (Marques et al. 2017) to be associated with poorer self-rated health, with even stronger associations than depressive symptoms, substance use, diet or academic achievement (Piko 2007).

Less is known about the longitudinal associations between measured physical fitness characteristics and self-rated health. Two studies recently explored these associations with contradictory findings. Hanssen–Doose et al. (2020) reported muscular strength and coordination, but not cardiorespiratory fitness, to explain future self-rated health. However, a study by Padilla–Moledo et al. (2020) found cardiorespiratory fitness and a multicomposite fitness index to have longitudinal associations with self-rated health, but not muscular strength. More research is needed to clarify which fitness components are related to future self-rated health and to examine whether this association persists after adjusting for physical activity.

3 PURPOSE OF THE THESIS

This study entity was designed to provide novel information related to the Move! – monitoring system for physical functional capacity, and to help the interpretation of the results on a practical level and to estimate the health-related associations between Move! measurements and self-rated health. This study entity examined factors associated with fitness development, and fitness development at the individual level and in adolescents with impairments in physical fitness. The detailed aims of the original studies are as follows:

I This study aimed to examine and quantify the associations of body composition, physical activity and sedentary time with the Move! measurements in a cross-sectional study design in adolescents.

II This study aimed to recognise the essential factors of natural fitness development during adolescence by exploring the associations of body composition, physical activity, maturity and fitness development in a 2-year follow-up study. Special reference was aimed at adolescents with low initial physical fitness.

III The main aim of this study was to predict unfavourable 20-m shuttle run test status during adolescence on the individual level. This study utilised a machine learning approach and a 2-year follow-up study design. A secondary aim was to evaluate, using a data-driven approach, the best predictors of unfavourable 20-m shuttle run test prospects. Additionally, the predictive modelling algorithms developed in this study were made available to support future precision exercise medicine research.

IV This study aimed to examine the longitudinal associations of physical activity, physical fitness and self-rated health, independent of adiposity, societal status and maturity status, separately for adolescent girls and boys. The hypothesis was that physical activity and physical fitness would independently explain future self-rated health.

4 MATERIALS AND METHODS

4.1 Study design and participants

4.1.1 Research entity

This thesis is a part of a larger study entity related to the Finnish Schools on the Move programme (Blom et al. 2018), and 1778 students from nine Finnish schools from grades 4–7 were invited to participate in a longitudinal study (2013–2015) (Figure 6), and 970 students (55%) delivered a signed written consent with their main carer and participated. Participation was voluntary and could be discontinued at any point during the research.

Data points used in this study entity included the baseline measurements of 2013 and the follow-up measurements with 1-year intervals in 2014 and 2015 (Figure 6). The measurements were conducted between 14 January 2013 and 20 May 2015 and within the same calendar week in each school during the two-year follow-up. Physical activity measurements were informed during school day and conducted in student's habitual environments. All other measurements were conducted on school premises during the school day. All measurements were performed by trained personnel and conducted following the Declaration of Helsinki. The study setting for the measurements was approved by the Ethics Committee of the University of Jyväskylä.

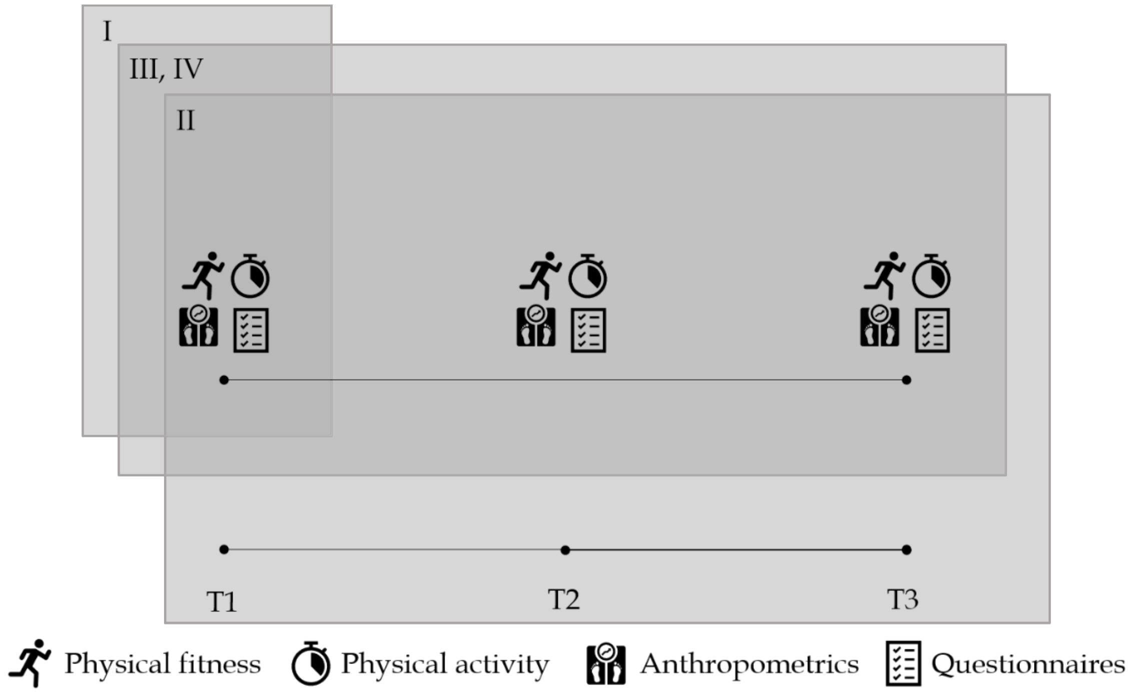

FIGURE 6. Overall study design and data points used in different sub-studies

4.1.2 Participants

Studies I–IV utilised different study populations depending on the research aim. Study I utilised a cross-sectional sample from the baseline measurements 2013 (Time Point 1, T1). After excluding students with no valid physical activity data (n = 204), missing physical fitness measurements (n = 76) and possible confounding factors (reported injuries, illnesses, learning difficulties or disabilities, n = 97), the final study population comprised 594 apparently healthy students (56%), aged 9–15 (12.4 ± 1.3) years old. Study II utilised data from all participants from baseline (n = 971, T1) and from 1-year (2014, T2) and 2-year follow-up (2015, T3). Study III utilised data from all participants from baseline (n = 971, T1) and from 2-year follow-up (2015, T3). This sample was reduced to 633 participants (50% girls) when individuals with no data from the 20-m shuttle run test were excluded. Study IV utilised baseline measurements (T1) and the 2-year follow-up (T3) from a sample of 7th grade participants at baseline (n = 256, 58% girls, 13.7 ± 0.3 years old).

4.2 Assessments

4.2.1 Physical fitness

Physical fitness was assessed with the measurements included in the Move! system (Jaakkola et al. 2012). The measurements were conducted in the school's gym halls. The reliability of the measures used was reasonable (Jaakkola et al. 2012). Measurements were performed for one student group (avg. 25 persons) during a 1.5 h session. The measurement techniques were explained and rehearsed prior to the official assessment.

Cardiorespiratory fitness (Figure 7) was evaluated with a 20-m shuttle run where running speed was increased in 1-minute intervals until maximal voluntary exhaustion. Initial speed was 8.0 km · h^{-1}, following speed 9.0 km · h^{-1} and following increments of 0.5 km · h^{-1} per stage (Nupponen et al. 1999). Result was counted as the number of laps run.

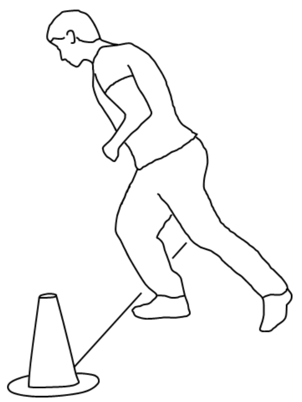

FIGURE 7. 20-m shuttle run

Muscular fitness measurements included push-up and curl-up. *Push-up* (Pihlainen et al. 2008, 43) measures upper-body muscular strength (Figure 8). Hand positions during measurement were standardised. Participants were in a prone position, palms placed on the ground and in line with the shoulders. The hands were in the right position when fingers were placed pointing forward, and shoulders could be reached with thumbs. Measurement started from the upper push-up position where arms fully extended, the torso was straight and the feet hip-width apart. Boys had their toes on the ground, and girls had their knees on the ground. The angle of the hips was 160–180°, and the head was in line with the body. Students lowered their bodies until the humerus was horizontal and then pushed back up. Optionally, a 10-cm-height object may be placed under the chest to help the assessment. Students completed as many push-ups as possible in one minute. The result was the number of correctly performed push-ups during the allowed time.

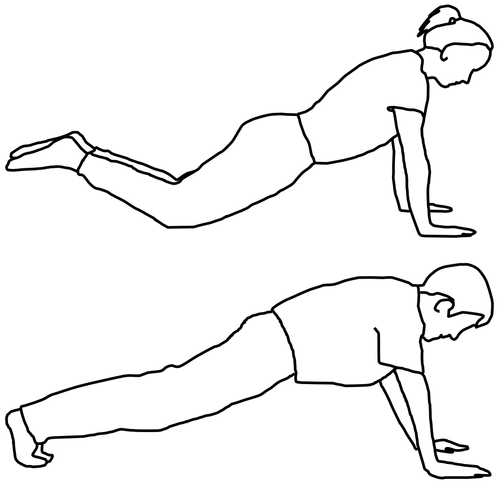

FIGURE 8. Push-up

Curl-up (Jaakkola et al. 2012) is a modified version of FitnessGram curl-up and measures abdominal strength (Figure 9). The number of correctly performed repetitions is counted with a maximal number of repetitions limited to 75. An 8-cm wide measurement area was marked on a mattress for those in the 5th grade (approx. 11 years old) and a 12 cm area for 8th grade (approx. 14 years old) students. Students were placed in a supine position with a knee angle of approximately 100°. Arms were straight and parallel to the trunk. Palms faced the mattress, and fingers were stretched out touching the nearest edge of the measurement area. The head rested on the mattress on top of a paper and heels were on the ground. Students performed curl-ups according to a cadence from a sounded signal (30 repetitions/min). The cadence was slightly faster than in the FitnessGram curl-up test (20 repetitions/min). Students slid fingers on the opposite edge of the measurement strip, while heels stayed on the ground. Students returned to the starting position and repeated the procedure until they could not perform the measurement according to selected criteria. The number of correctly performed curl-ups was counted up to a maximum of 75 (Jaakkola et al. 2012).

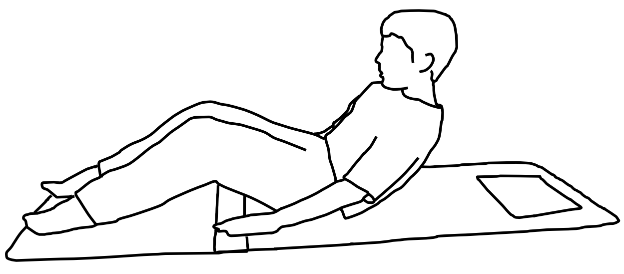

FIGURE 9. Curl-up

Flexibility (Jaakkola et al. 2012) is a composite score comprising four measurements assessing multi-joint flexibility (Figure 10). Measurements included squat, lower back extension and left and right shoulder stretch. Each student received 1 point out of each measurement that he/she performed according to the selected criteria. The maximum score in flexibility was 4 and minimum 0.

In the *squat*, students were instructed to stand upright, with legs shoulder-width apart. Students raised their arms straight up and squatted as low as they could while keeping their back extended, knees behind the toe line, hip angle above 45°, heels on the ground, and feet and knees shoulder-width apart. A result of '1' was recorded if the students reached a knee angle ≤ 90° and '0' if the knee angle was > 90° and/or students could not keep the proper position.

In the *lower back extension* in sitting posture, students were instructed to sit on the floor on their ischial tuberosities, with both legs extended. Hands were placed on top of the legs. Students attempted to extend their lower back while keeping their legs extended and hands stationary. Results were marked as '1' if student's lower back was extended and as '0' if the lower back was not extended and/or students could not keep the proper position.

In the *shoulder stretch*, the students were instructed to stand in an upright position with their back extended. Students extended their right arm straight up and flexed their left arm between their shoulder blades. Students attempted to reach their fingers together by flexing the right arm calmly towards the shoulder blades while keeping their back in a neutral position. The measurement was then repeated with the hands in opposite roles. Results were recorded for both sides. The upper hand determined the side of the measurement (e.g., the right hand up corresponded to a measurement of the right side). Results were marked as '1' if students could reach their fingers together and as '0' when students could not reach their fingers together and/or students could not keep the proper position (Jaakkola et al. 2012).

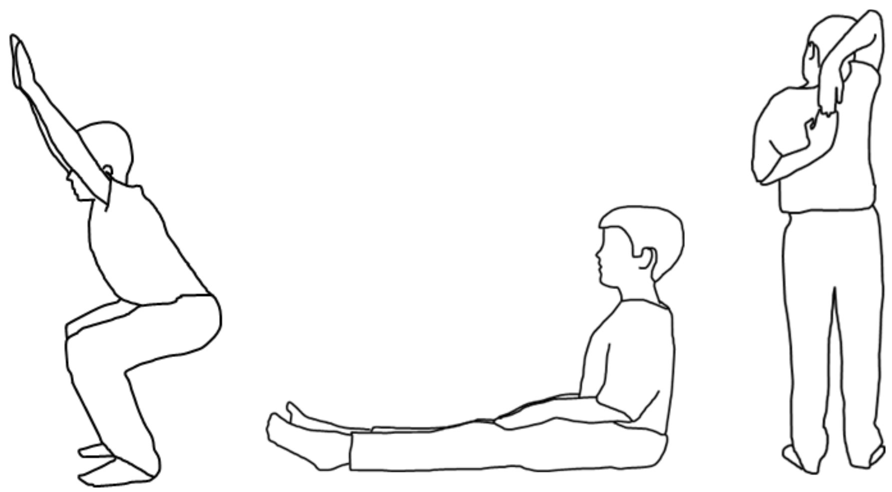

FIGURE 10. Flexibility measurements include squat (left), lower back extension (centre) and shoulder stretch (right)

Fundamental movement skills (FMS) were evaluated with the 5-leaps test and throwing-catching combination test. The *5-leaps test* (Jaakkola et al. 2009) assesses movement skills (Figure 11). Students performed five consecutive leaps. The first leap was performed behind a marked line with both legs (1), followed by four alternating single-leg leaps (2–5). Landing was performed on both legs (6). The measurement was performed either on a gymnastic mat without shoes or on the floor with shoes. Students had two attempts to jump as far as they could. The length of the performance was measured from the heel nearest to the starting line. The best result was recorded with 0.1 m accuracy and rounded downwards to the nearest tenth (e.g., 817 cm corresponded to 8.1 m) (Jaakkola et al. 2012).

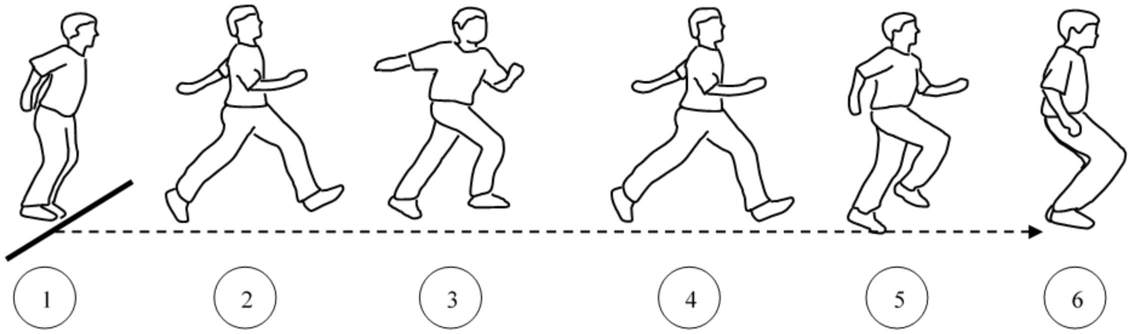

FIGURE 11. 5-leaps test

The throwing-catching combination test (Jaakkola et al. 2012) assessed object control skills (Figure 12). A 1.5 m x 1.5 m sized target area was marked on the wall with the lower border 0.9 m above the floor. Students threw a tennis ball with an overhand throw (1) in an attempt to hit the target area (2) and catch the ball after one bounce (3). Throwing distances were 7 m and 8 m for 5th and 8th grade girls, respectively, and 8 m and 10 m for 5th and 8th grade boys, respectively. The number of correctly performed attempts out of 20 were counted (Jaakkola et al. 2012).

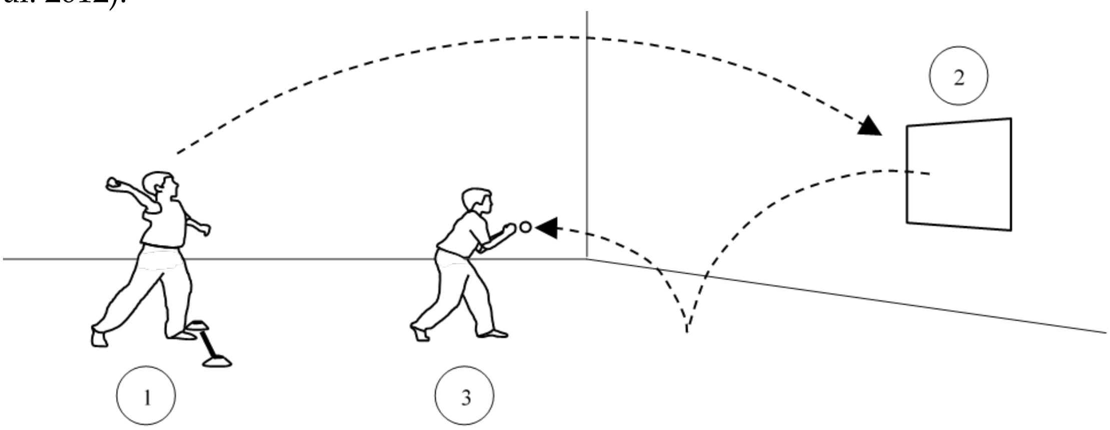

FIGURE 12. Throwing-catching combination test

4.2.2 Physical activity

Objective measurements of physical activity and sedentary time (ST) were conducted using an accelerometer (ActiGraph GT3X+, wGT3X+, Pensacola, Florida, USA) for seven consecutive days. Participants were advised to continue their ordinary daily routines during the measurement period and instructed to wear the accelerometer on the right side of the hip during waking hours, except for water activities (e.g. shower, swimming). Data were collected in raw 30 Hz acceleration, standardly filtered, and converted into 15 s epoch counts. Period of ST (≤ 100 counts per minute (cpm)) and moderate-to-vigorous physical activity (MVPA) (≥ 2296 cpm) (Evenson et al. 2008) were defined from the data. Periods exceeding 30 min of consecutive zero counts were defined as non-wear time (Domazet et al. 2016). Data over 20,000 cpm were considered spurious acceleration and excluded (Heil et al. 2012). The minimum amount of adequate data was set as 500 $min \cdot day^{-1}$ (between 7 am and 11 pm) (Cooper et al. 2015) for at least two weekdays and one weekend day. MVPA and ST were converted into a weighted mean value of MVPA and ST per day (e.g., [(average MVPA $min \cdot day^{-1}$ of weekdays × 5 + average MVPA $min \cdot day^{-1}$ of weekend × 2) / 7]).

4.2.3 Anthropometrics

Body height was measured with an accuracy of 0.1 cm (Charder HM 200P scale, Taichung City, Taiwan). Body composition and weight were measured in light clothing using bioelectrical impedance analysis (InBody 720, Biospace Co., Ltd) prior to participating in the physical fitness measurements. Fat percentage, body mass index (BMI, $kg \cdot m^{-2}$), fat mass index (FMI, $kg \cdot m^{-2}$) and fat-free mass index (FFMI, $kg \cdot m^{-2}$) were calculated (mass in kilograms divided by height in meters squared). Waist circumference was measured from the midpoint between the lower edge of the last palpable rib and the top of the iliac crest at the end of a normal expiration according to the WHO guidelines (World Health Organization 2008).

4.2.4 Questionnaires

Maturity. Students self-assessed their biological maturation status with a questionnaire utilising line drawings of external primary and secondary sex characteristics, categorised by the Tanner scale (Tanner 1962; Taylor et al. 2001). Pubertal status was assessed with two questions: (1) the developmental stage of testicles/breasts and (2) pubertal hair on a scale of 1–5.

Self-rated health was measured by asking adolescent's perceptions of their current health with a questionnaire: 'What do you think about your health? It is…? Very good, good, fair, or poor.' Because of the low prevalence of poor ratings, the adolescents were grouped into three: very good, good, and fair or poor groups. Self-rated health survey is reportedly reliable in adolescents (Boardman 2006). The test-retest analysis in our sample showed an intraclass correlation (ICC) of 0.60 (95% confidence interval 0.36–0.77, $p < 0.001$) for boys and 0.60 (0.41–0.73, $p < 0.001$) for girls for answers given two weeks apart.

4.2.5 Additional measurements

Adding to basic demographic information (age and sex), the questionnaires assessed student's perceptions of their physical, psychological and social status and health-related behaviour, e.g. subjective evaluation of physical activity (Booth et al. 2001), and societal status of the family (Rajala et al. 2019).

Questionnaire to guardians. The main carer was asked to report any injuries, illnesses or disabilities affecting the child's physical activity, physical fitness and/or school performance. This information was used in Study I to exclude participants with possible confounding factors.

Academic scores (teacher-rated grade points) included grade point average (GPA) and grade points in physical education. The data were provided by regional education services.

4.3 Statistical approaches

In this summary, the main statistical approaches are presented. The interested reader is advised to find more detailed information on statistical procedures from the original articles. In this study entity, the IBM© SPSS© Statistics was used (IBM 2016) for basic analyses (normal distribution, means, standard deviations, correlations, t-tests, ANOVA and regression models). Further analyses were conducted using the Mplus statistical package (Muthén & Muthén 2017) or MATLAB R2018a with the Statistics and Machine Learning Toolbox (The MathWorks, Inc., Natick, Massachusetts, United States). Missing data were assumed to be missing at random (MAR). Analyses were conducted separately for boys and girls. Statistical significance level was set at $P \leq 0.05$.

In Study I, a linear regression model was used to explore the associations of selected variables and physical fitness. The final multivariable model comprised age, fat mass index, fat-free mass index, moderate-to-vigorous physical activity and sedentary time with physical fitness component as the dependent factor. Fat mass index and fat-free mass index were chosen for indicators of body composition, as these measures were not too highly correlated and could be placed in the same regression model. The sedentary time was proportional to device-wearing time, and additionally, the variation produced by moderate-to-vigorous physical activity was removed. For physical fitness measures, where the testing procedures varied between age groups, the results were transformed into a standardised z-score. The unmodified data were shown for clarity. Standardised regression coefficients (Stand. β) were used to indicate the direction of the associations and their comparable strength, and coefficients of determination (R^2) to indicate the model's explanatory rate. The unstandardised regression coefficients (Unstand. β) were used to calculate practically relevant associations between body composition, physical activity and physical fitness.

In Study II, a latent growth curve modelling was used to study physical fitness development over time (Spring 2013, 2014 and 2015; T1, T2 and T3, respectively) among boys and girls. In the fully adjusted model, the variation in the level (initial level) and slope (rate of change over time) of physical fitness was explained by age, pubertal status, fat mass index and fat-free mass index, and moderate-to-vigorous physical activity at baseline (T1) and by the absolute change between T1 and follow-up T3 (Δ) in fat mass index, fat-free mass index, and moderate-to-vigorous physical activity. Finally, the students were divided into tertiles according to their results in each of the fitness measurement at baseline. The lowest tertile group was named the low fit group and their fitness development patterns were compared against the whole population.

In Study III, a random forest machine learning algorithm was used to predict future fitness status. The analysis process included data preprocessing, data division, training and prediction, and estimation of the direction of the associations described in detail in the original article. Forty-eight baseline variables, including questionnaires (demographics, physical, psychological, social and lifestyle factors), objective measurements (anthropometrics, fitness characteristics, physical activity, body composition), and academic scores were utilised in the study.

In Study IV, cross-lagged path analyses were completed. In these analyses, both the cross-sectional and longitudinal associations between physical activity, physical fitness and self-rated health were assessed, independently of covariates. In the final models, the baseline values of overall physical fitness index (average of sex-specific z-scores from all fitness measurements), moderate-to-vigorous physical activity and self-rated health rating explained the follow-up values of the same variables, independently of baseline body fat percentage and pubertal status. Additionally, the cross-sectional and longitudinal associations of each fitness characteristic with self-rated health were separately analysed.

5 OVERVIEW OF THE RESULTS

5.1 Descriptives of the study population

At baseline, participants (n = 970) were 12.6 (± 1.3) and 12.5 (± 1.3) years old (boys and girls, respectively). Boys were on average 156.7 cm tall and weighed 46.5 kg, while girls were 155.5 cm tall and 46.5 kg. Average BMI in boys was 18.6 and 19.1 $kg \cdot m^{-2}$ in girls. Fat percentage was 15.3% in boys and 21.2% in girls. The prevalence of overweight or obesity was 15% and 14% at baseline in boys and girls, respectively. Pubertal status was on average 2.7 in boys and 2.6 in girls at baseline.

Participants had 59.2 and 47.5 $min \cdot day^{-1}$ MVPA, of which 19.6 and 15.6 $min \cdot day^{-1}$ was vigorous (boys and girls, respectively). Boys were sedentary 63.0% and girls 66.3% of the time they wore the accelerometer. Boys reported to be physically active for more than one hour 6.1 times per week and girls 5.5 times per week. Thirty-four (34)% of boys and 20% of girls complied with the physical activity guidelines for children and youth (at least 60 min of MVPA per day) (Bull et al. 2020) at baseline. Average self-rated health was 2.3 in boys and 2.2 in girls at baseline, with 92.2% of boys and 90.1% of girls describing their self-rated health to be good or excellent. Further descriptive statistics are presented in Table 3.

TABLE 3. Descriptives of the study sample at baseline.

	Boys (n=462)	Girls (n=508)
Age (years)	12.6 ± 1.3	12.5 ± 1.3
Physical fitness		
CRF (20-m shuttle run, laps)	47.5 ± 20.3	37.0 ± 15.9
MF (Push-up, repetitions)[a]	16.7 ± 11.7	23.9 ± 13.2
MF (Curl-up, repetitions)	39.5 ± 20.1	34.7 ± 19.9
FMS (5-leaps test, m)	8.5 ± 1.2	8.0 ± 1.0
FMS (TCCT, repetitions)	12.6 ± 5.0	11.5 ± 4.8
Flexibility (sum of four measurements)	3.1 ± 1.0	3.4 ± 0.8
Physical activity		
Accelerometer wear time ($min \cdot day^{-1}$)	765.3 ± 56.1	773.6 ± 53.9
MVPA ($min \cdot day^{-1}$)	59.2 ± 23.7	47.5 ± 18.4
VPA ($min \cdot day^{-1}$)	19.6 ± 12.5	15.6 ± 11.0
Prevalence of MVPA ≥ 60 $min \cdot day^{-1}$ (n, (%))	159 (34%)	101 (20%)
Sedentary time (% of wear time)	63.0 ± 0.7	66.3 ± 0.7
Self-reported PA (days per week with PA > 60 min)	6.1 ± 1.9	5.5 ± 1.8
Anthropometrics, body composition and maturity		
Height (cm)	156.7 ± 11.3	155.5 ± 9.5
Weight (kg)	46.5 ± 12.7	46.5 ± 10.6
BMI ($kg \cdot m^{-2}$)	18.6 ± 3.3	19.1 ± 3.2
Prevalence of overweight and obesity[b] (n, (%))	62 (15%)	69 (14%)
FMI ($kg \cdot m^{-2}$)	3.1 ± 2.3	4.2 ± 2.3
FFMI ($kg \cdot m^{-2}$)	15.6 ± 1.8	14.8 ± 1.4
Fat% (%)	15.3 ± 8.2	21.2 ± 7.5
Pubertal status[c]	2.7 ± 1.0	2.6 ± 0.9
Self-rated heath (avg. score)	2.3 ± 0.6	2.2 ± 0.6
Prevalence of good or excellent self-rated health (n, (%))	426 (92%)	458 (90%)

Units are means and standard deviations unless other mentioned; CRF, Cardiorespiratory fitness; MF, Muscular fitness; FMS, Fundamental movement skills; TCCT, Throwing-catching combination test; MVPA, Moderate-to-vigorous physical activity; VPA, Vigorous physical activity; PA, Physical activity; BMI, Body mass index; FMI, Fat mass index; FFMI, Fat-free mass index; [a] The measurement technique differed between boys and girls; [b] Classification was based on Cole's thresholds; [c] Classification was based on self-assessment questionnaire and Tanner's scale.

5.2 Correlates of physical fitness in adolescents

In Study I, we analysed the associations between body composition, physical activity and physical fitness characteristics. The directions, significances and comparable strengths of these associations (fat mass index, fat-free mass index, MVPA and sedentary time with physical fitness) can be seen for boys and girls from standardised regression coefficients (Stand. β) in Figures 13–16. For boys and girls, respectively, the regression model explained (R^2) 45.5% and 34.1% of the variance in cardiorespiratory fitness. For muscular fitness the R^2 values were 37.4% and 30.2%, 18.0% and 13.8% for push-up and curl-up in boys and girls, respectively. The regression model explained 6.1% and 5.1% of the variance in flexibility for boys and girls, respectively. For fundamental movement skills the R^2 values were 67.8% and 47.4%, 17.6% and 11.6% for 5-leaps test and throwing-catching combination test for boys and girls, respectively (related information in the original manuscript (Study I)). In general, fat mass index was negatively associated, while fat-free mass index and MVPA had positive associations with physical fitness. Sedentary time had no statistically significant association with any of the fitness components (Figures 13–16).

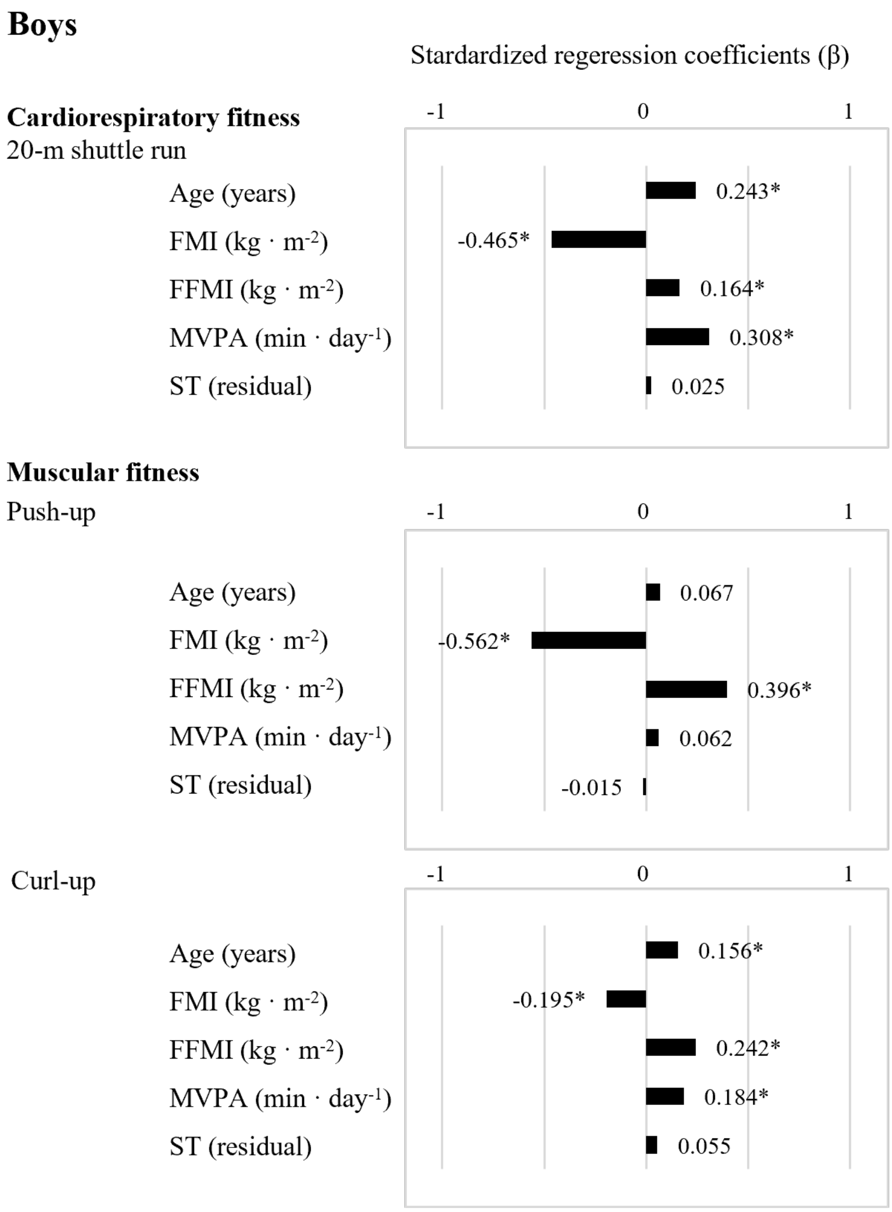

FIGURE 13. Direction, significance and comparable strength for the cross-sectional associations of body composition and physical activity with cardiorespiratory and muscular fitness in boys. FMI, Fat mass index; FFMI, Fat free mass index; MVPA, Moderate-to-vigorous physical activity; ST residual, Sedentary time value where variation produced by MVPA and device wearing time is removed. *, Statistical significance level P<0.05

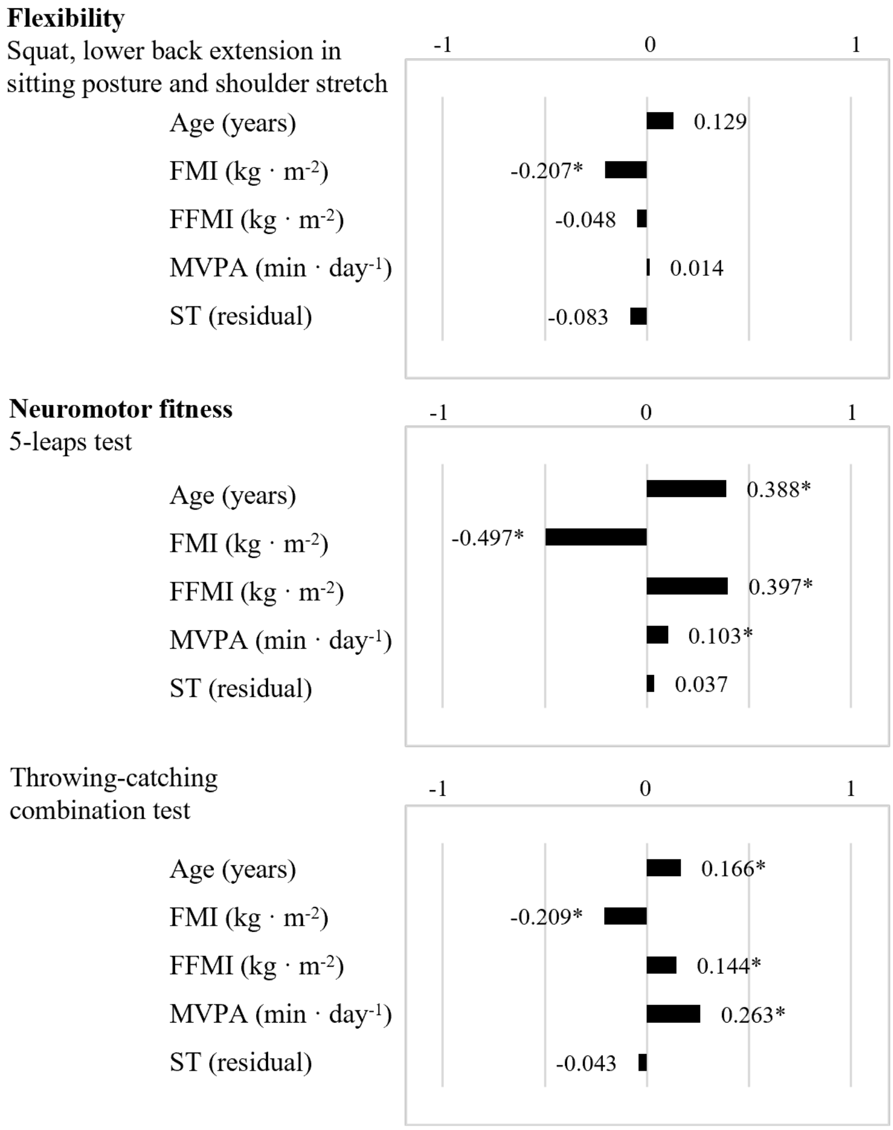

FIGURE 14. Direction, significance and comparable strength for the cross-sectional associations of body composition and physical activity with flexibility and neuromotor fitness in boys. FMI, Fat mass index; FFMI, Fat free mass index; MVPA, Moderate-to-vigorous physical activity; ST residual, Sedentary time value where variation produced by MVPA and device wearing time is removed. *, Statistical significance level P<0.05

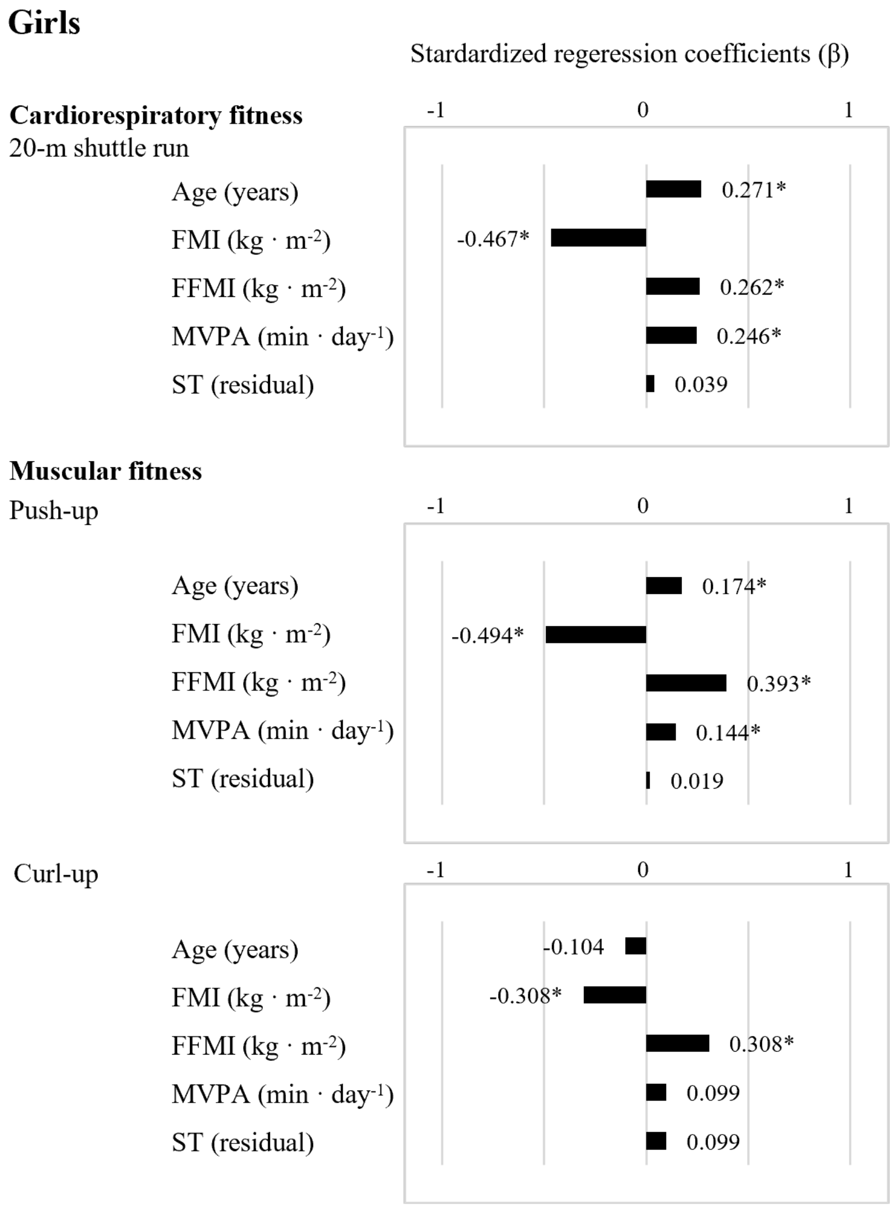

FIGURE 15. Direction, significance and comparable strength for the cross-sectional associations of body composition and physical activity with cardiorespiratory and muscular fitness in girls. FMI, Fat mass index; FFMI, Fat free mass index; MVPA, Moderate-to-vigorous physical activity; ST residual, Sedentary time value where variation produced by MVPA and device wearing time is removed. *, Statistical significance level P<0.05

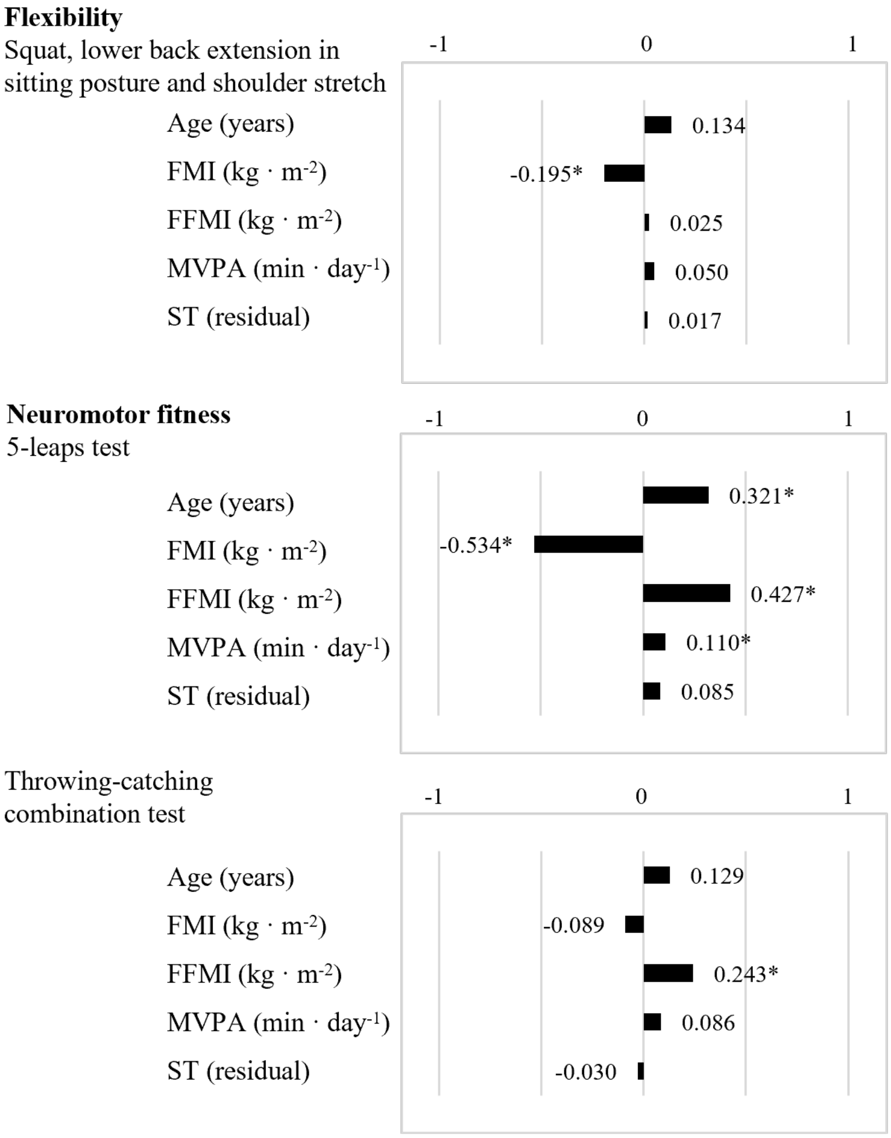

FIGURE 16. Direction, significance and comparable strength for the cross-sectional associations of body composition and physical activity with flexibility and neuromotor fitness in girls. FMI, Fat mass index; FFMI, Fat free mass index; MVPA, Moderate-to-vigorous physical activity; ST residual, Sedentary time value where variation produced by MVPA and device wearing time is removed. *, Statistical significance level P<0.05

5.2.1 Cardiorespiratory fitness

20-m shuttle run. Fat mass index had the strongest association with the 20-m shuttle run test in boys and girls (P<0.001 and P<0.001, respectively). Additionally, MVPA (P<0.001, P<0.001) and fat-free mass index (P=0.003, P<0.001) also had significant associations in both genders (Figures 13 and 15). In this study, we also estimated the practical associations with the linear regression model (Table 4). The unstandardised regression coefficients showed that an approximately 5 kg increase in fat mass in a 155-cm tall adolescent (the mean height of this study sample) was equivalent to 8 laps lower performance in the 20-m shuttle run test in boys and girls. Similar increase in fat-free mass corresponded to +4 and +6 laps, and a 10-min increase in daily MVPA +3 and +2 laps resulted in higher results in boys and girls, respectively (Table 4).

5.2.2 Muscular fitness

Push-up. Fat mass index had the strongest association with push-ups in boys and girls (P<0.001 and P<0.001, respectively). Also, only fat-free mass index (P<0.001) was associated with push-up in boys, while, in girls, fat-free mass index (P<0.001) and MVPA (P=0.005) also had significant associations (Figures 13 and 15). Approximately 5 kg increase in fat mass was equivalent to -6 repetitions in push-up in both sexes. Similar increase in fat-free mass corresponded to +5 and +8 repetitions in boys and girls, respectively. Ten minutes increase in daily MVPA was equivalent to +1 repetition in girls, while, in boys, the association was not statistically significant (Table 4).

Curl-up. Fat-free mass index had the strongest association with curl-up in boys (P=0.001). Additionally, fat mass index (P=0.003) and MVPA (P=0.002) were associated with curl-up in boys (Figures 13 and 15). In girls, fat mass index and fat-free mass index were equally associated (P<0.001). No other statistically significant associations were observed in girls. Approximately 5 kg increase in fat mass was equivalent to -4 and -6 repetitions in curl-up in boys and girls, respectively. Similar increase in fat-free mass corresponded to +6 and +9 repetitions in boys and girls, respectively. Ten minutes increase in daily MVPA corresponded to +2 repetitions in boys, while the association was not statistically significant in girls (Table 4).

5.2.3 Fundamental movement skills

5-leaps test. Fat mass index had the strongest association with 5-leaps test in boys and girls (P<0.001 and P<0.001, respectively). Fat-free mass index (P<0.001, P<0.001) and MVPA (P=0.005, P=0.030) were also associated in both genders (Figures 14 and 16). Approximately 5 kg increase was equivalent to -60 cm in the 5-leaps test in both sexes. Similar increase in fat-free mass was equivalent to +60 cm in boys and girls. Ten minutes increase in daily MVPA corresponded to +10 cm in boys and girls (Table 4).

Throwing-catching combination test. In boys, MVPA had the strongest association with throwing-catching combination test (P < 0.001), with fat mass index (P<0.001) and fat-free mass index (P=0.030) also associated. In girls, only fat-free mass index (P<0.001) had a statistically significant association (Figures 14 and 16). Although these associations were statistically significant, the practical associations were minor and corresponded to 1–2 repetitions in the throwing-catching combination test in both sexes (Table 4).

5.2.4 Flexibility

Flexibility. Fat mass index was the only factor associated with flexibility in both boys and girls (P=0.001, P=0.001, respectively) (Figures 14 and 16). Also, the practical associations of fat were minor and corresponded to less than one (< −1) score point in flexibility (Table 4).

TABLE 4. Estimated practical associations of fat, fat-free mass and moderate-to-vigorous physical activity (MVPA) with physical fitness.

	Boys	Girls
Cardiorespiratory fitness		
20-m shuttle run	laps	
+ 5 kg Fat mass[a]	−8	−8
+ 5 kg Fat-free mass[a]	+4	+6
+ 10 min MVPA · day^{-1}	+3	+2
Muscular fitness		
Push-up	repetitions	
+ 5 kg Fat mass[a]	−6	−6
+ 5 kg Fat-free mass[a]	+5	+8
+ 10 min MVPA · day^{-1}	ns	+1
Curl-up	repetitions	
+ 5 kg Fat mass[a]	−4	−6
+ 5 kg Fat-free mass[a]	+6	+9
+ 10 min MVPA · day^{-1}	+2	ns
Flexibility	flexibility score	
+ 5 kg Fat mass[a]	< −1	< −1
+ 5 kg Fat-free mass[a]	ns	ns
+ 10 min MVPA · day^{-1}	ns	ns
Fundamental movement skills		
5-leaps test	cm	
+ 5 kg Fat mass[a]	−60	−60
+ 5 kg Fat-free mass[a]	+60	+60
+ 10 min MVPA · day^{-1}	+10	+10
Throwing-catching combination test	repetitions	
+ 5 kg Fat mass[a]	−1	ns
+ 5 kg Fat-free mass[a]	+1	+2
+ 10 min MVPA · day^{-1}	+1	ns

Unstandardised regression coefficients of the linear regression model were transformed to relevant measurement related values and rounded to nearest integer. [a] Increase by two units in fat mass index or two units in fat-free mass index were equivalent to 4.8 kg (approximately 5 kg) of fat or correspondingly fat-free mass in a 155 cm tall child. < 1 indicates that the association was statistically significant but corresponds to less than one unit in physical fitness. ns, association was not statistically significant. MVPA, moderate-to-vigorous physical activity.

5.3 Physical fitness development during adolescence

In Study II, physical fitness development during adolescence was assessed. Special focus was addressed for those with low initial PF status. In some of the Move! measurements, the test instructions change with age, e.g. the throwing distance is longer for older participants in the throwing-catching combination test. Only such Move! measurements were included in Study II, where either the measurement instructions did not change with age and reasonable statistical associations were observed in the cross-sectional design. Figure 17 presents the mean values for cardiorespiratory fitness (20-m shuttle run), muscular fitness (push-up) and fundamental movement skills (5-leaps test) during the 2-year observational period with 95% confidence intervals.

Physical fitness increased during the 2-year observational period in both sexes. The trend was linear in the normal population in fundamental movement skills among boys and in cardiorespiratory and muscular fitness among girls. The trend was quadratic, that is, an increment following a plateau in cardiorespiratory and muscular fitness among boys and in fundamental movement skills among girls (Figure 17).

The physical fitness development followed a similar pattern in the low fit group (those in the lowest fitness tertile at baseline). Furthermore, the physical fitness of the low-fit group remained significantly lower throughout the observation period. Boys and girls with low initial fitness also had statistically low fitness status after 1 and 2 years compared with the whole population (in T2 and T3, respectively, no observed overlaps in the 95% CI, Figure 17).

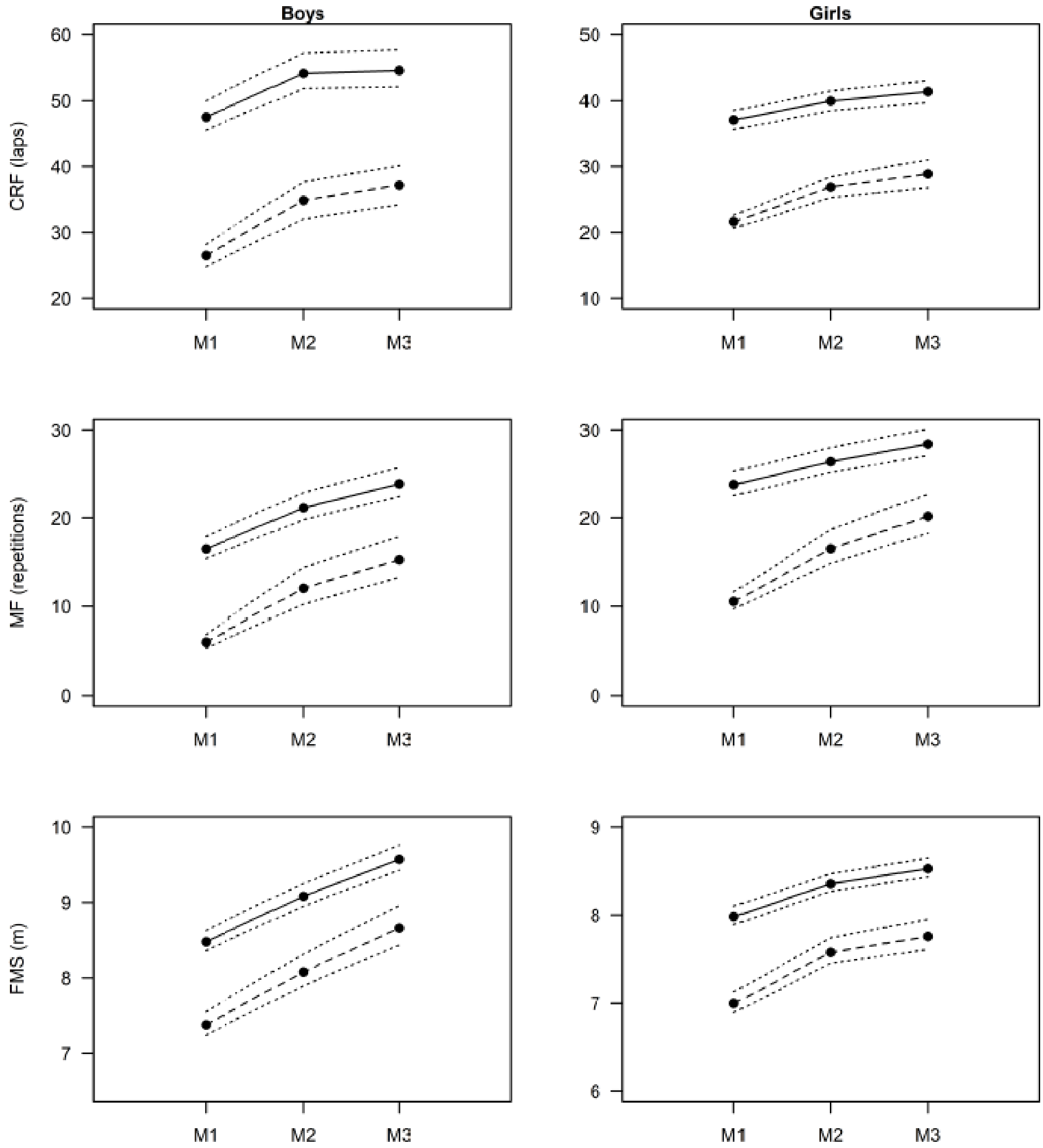

FIGURE 17. Physical fitness development in adolescents in 2 years in the normal population (solid line) and in the low fit group (Physical fitness in the lowest tertile at baseline (dashed line)). Dotted lines represent the 95% confidence intervals. CRF, Cardiorespiratory fitness; MF, Muscular fitness; FMS, Fundamental movement skills. M1–3, Measurement Time Points 1–3 (T1–T3)

5.3.1 Factors explaining physical fitness development

5.3.1.1 Cardiorespiratory fitness

Of the baseline measures (fat mass index, fat-free mass index, MVPA and pubertal status), only fat mass index showed a statistically significant association with the cardiorespiratory fitness development in boys (standardised regression coefficient −0.17, P=0.007), indicating that a high initial amount of adiposity predicted a negative development in cardiorespiratory fitness in boys. No association between baseline measures and cardiorespiratory fitness development was observed in girls (Table 5).

The change in fat mass index had an inverse association with cardiorespiratory fitness development in both boys and girls (−0.35, P<0.001 and −0.34, P<0.001, respectively). This association was strongest in the model, indicating that an increase in adiposity considerably attenuated cardiorespiratory fitness development. The change in fat-free mass index was associated with cardiorespiratory fitness development only in girls (0.15, P=0.028) and the change in MVPA only in boys (0.25, P=0.015) (Table 5).

5.3.1.2 Muscular fitness

Baseline pubertal status and fat-free mass index had positive associations with muscular fitness development in boys (0.23, P=0.025 and 0.28, P=0.010), indicating that advanced pubertal status and higher amounts of fat-free mass predicted a positive development in muscular fitness. No significant associations between baseline measures and muscular fitness development were observed in the girls (Table 5).

The changes in body composition showed significant associations with muscular fitness development. Change in fat-free mass index showed positive associations in boys and girls (0.25, P=0.004 and 0.16, P=0.037, respectively), indicating that increases in fat-free mass were associated with positive muscular fitness development. The change in fat mass index was significantly and inversely associated only in boys (−0.36, *P*=0.001). No significant associations were observed between changes in MVPA and muscular fitness development (P=0.80 in boys and P=0.061 in girls) (Table 5).

5.3.1.3 Fundamental movement skills

Baseline body composition had significant associations with fundamental movement skills development in boys (fat mas index −0.24, P=0.001 and fat-free mass index 0.20, P=0.022), indicating that high levels of initial adiposity explained adverse fundamental movement skill development and high levels of initial fat-free mass on the contrary. No significant associations between baseline measures and fundamental movement skill development were observed in the girls (Table 5).

Changes in fat mass index had strong and negative associations with fundamental movement skill development in both boys (−0.63, *P*<0.001) and girls (−0.37, *P*<0.001). Change in fat-free mass index showed positive associations in boys (0.28, *P*<0.001) but not in girls. No associations were observed with changes in MVPA (Table 5).

TABLE 5. Associations of body composition and moderate-to-vigorous physical activity (MVPA) with physical fitness development in boys and girls.

	Boys		Girls	
CRF slope	**B (SE)**	**P value**	**B (SE)**	**P value**
Pube	0.12 (0.09)	0.19	−0.04 (0.10)	0.72
FMI	−0.17 (0.06)	**0.007**	−0.07 (0.08)	0.39
ΔFMI	−0.35 (0.07)	**<0.001**	−0.34 (0.10)	**<0.001**
FFMI	0.08 (0.10)	0.42	0.08 (0.08)	0.30
ΔFFMI	0.11 (0.07)	0.12	0.15 (0.07)	**0.028**
MVPA	0.09 (0.09)	0.28	0.14 (0.11)	0.18
ΔMVPA	0.25 (0.10)	**0.015**	0.17 (0.12)	0.18
R^2	0.20		0.24	
MF slope	**B (SE)**	**P value**	**B (SE)**	**P value**
Pube	0.23 (0.10)	**0.025**	0.09 (0.11)	0.40
FMI	−0.17 (0.09)	0.074	0.06 (0.07)	0.38
ΔFMI	−0.36 (0.11)	**0.001**	−0.12 (0.08)	0.13
FFMI	0.28 (0.11)	**0.010**	−0.10 (0.09)	0.26
ΔFFMI	0.25 (0.09)	**0.004**	0.16 (0.07)	**0.037**
MVPA	0.07 (0.15)	0.63	0.11 (0.09)	0.20
ΔMVPA	0.05 (0.20)	0.80	0.24 (0.13)	0.06
R^2	0.28		0.13	
FMS slope	**B (SE)**	**P value**	**B (SE)**	**P value**
Pube	0.12 (0.11)	0.25	−0.18 (0.10)	0.06
FMI	−0.24 (0.07)	**0.001**	−0.10 (0.08)	0.19
ΔFMI	−0.63 (0.11)	**<0.001**	−0.37 (0.10)	**<0.001**
FFMI	0.20 (0.09)	**0.022**	0.12 (0.10)	0.20
ΔFFMI	0.28 (0.07)	**<0.001**	0.16 (0.10)	0.10
MVPA	−0.05 (0.12)	0.68	0.04 (0.11)	0.70
ΔMVPA	−0.13 (0.19)	0.49	0.00 (0.13)	0.99
R^2	0.46		0.36	

All models were adjusted for age; Slope, Latent variable of the rate of change over time; CRF, Cardiorespiratory fitness (20-m shuttle run test); Pube, Pubertal status; FMI, Fat mass index; FFMI, Fat-free mass index; MVPA, Moderate-to-vigorous physical activity; Δ, difference score between measurements in Spring 2013 and Spring 2015; R^2, Coefficient of determination; MF, Muscular fitness (push-up); FMS, Fundamental movement skills (5-leaps test); B, Standardised regression coefficient; SE, Standard error

5.3.2 Individual development in cardiorespiratory fitness

In Study III, we assessed the individual development in cardiorespiratory fitness measured with the 20-m shuttle run test with machine learning. Table 6 presents the ability of the machine learning algorithm random forest to predict unfavourable future 20-m shuttle run test status based on 48 baseline variables. The area under the receiver operating characteristics curve (AUC) values were higher in girls (0.83) than in boys (0.76), both statistically higher than the random level of 0.5 (P<0.001). Sensitivity (individuals correctly predicted to belong to the lowest performance tertile) was higher in girls (0.80) than in boys (0.60). Specificity (individuals correctly predicted not to belong to the lowest performance tertile) was 0.78 in girls and 0.79 in boys.

TABLE 6. Performance of the random forest algorithm to predict unfavourable future 20-m shuttle-run test status.

	AUC (95 % CI)	*P* value	Sensitivity (95 % CI)	Specificity (95 % CI)
Girls	0.83 (0.76–0.90)	**< 0.001**	0.80 (0.69–0.91)	0.78 (0.74–0.82)
Boys	0.76 (0.71–0.81)	**< 0.001**	0.60 (0.52–0.68)	0.79 (0.74–0.84)

AUC, Area under the receiver operating characteristic curve; 95% CI, 95% Confidence interval; P value, statistical difference of the AUC value from the random level of 0.5; Sensitivity, Individuals correctly predicted to belong to the explored group; Specificity, Individuals correctly predicted not to belong to the explored group.

5.3.3 Best predictors of the 20-m shuttle run test prospects

Figures 18 and 19 present the statistically significant predictors for unfavourable future 20-m shuttle run test status. The x-axis in the figures shows variable importance, calculated using the increase or decrease in classification error when the predictor values were randomly permuted separately for each predictor. The higher the estimate, the higher the significance of the predictor. The top predictor was 20-m shuttle run test performance at baseline both in boys and girls (P<0.001, Figures 18 and 19), indicating that low initial 20-m shuttle run test performance predicted low performance also after two years.

Girls had 13 additional predictors (Figure 18): low performance in other physical fitness tests (5-leaps test (P<0.001), push-ups (P<0.001) and flexibility score (P=0.049)), high markers of adiposity (body fat percentage (P<0.001) and visceral fat (P<0.001)), low markers of physical activity (accelerometer-based counts (P<0.001), moderate-to-vigorous physical activity (P=0.003), reported participation to sport club practices (P=0.025) or competitions (P<0.001), and high percentage of accelerometer-based sedentary time (P=0.009)), low academic scores (grade point average and grade point in physical education, (both P<0.001)), and low perceived social status in school (P=0.015), all predicting placement in the lowest 20-m shuttle run test performance tertile after two years.

Adding to the baseline 20-m shuttle run test performance, boys had 19 additional predictors (Figure 19): low performance in other physical fitness tests (push-ups (P<0.001), 5-leaps test (P<0.001), throwing-catching combination test

(P<0.001), and curl-up (P=0.001)), high markers of adiposity (body fat percentage (P<0.001), visceral fat (P<0.001), waist circumference (P<0.001), weight (P<0.001), and BMI (P=0.005)), low academic scores (grade point in physical education (P<0.001), and grade point average (P=0.015)), low markers of physical activity (reported participation to sport club practices (P<0.001) or competitions (P=0.001), self-reported physical activity status (two questions: P<0.001 and P=0.006), and accelerometer-based MVPA (P=0.020)), low parents' willingness to help with schoolwork (P=0.045), low perceived fitness (P=0.007), and low life enjoyment (P=0.042), all predicting future placement in the lowest 20-m shuttle run test performance tertile after two years.

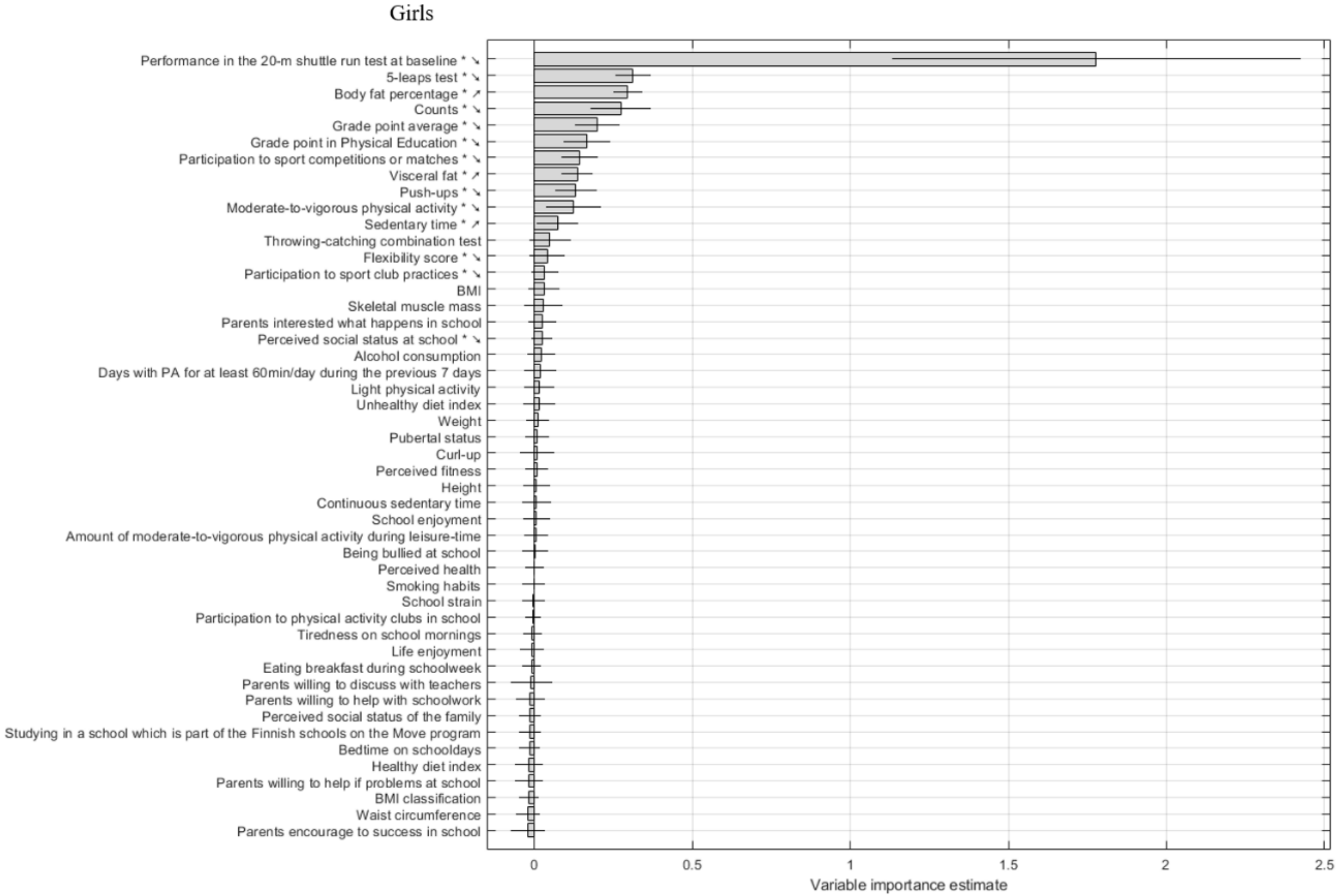

FIGURE 18. Best predictors for unfavourable 20-m shuttle run test prospects in girls. Statistically significant predictors are marked with * (P<0.05), and the direction of the association with arrows. The solid line represents the 95% confidence interval

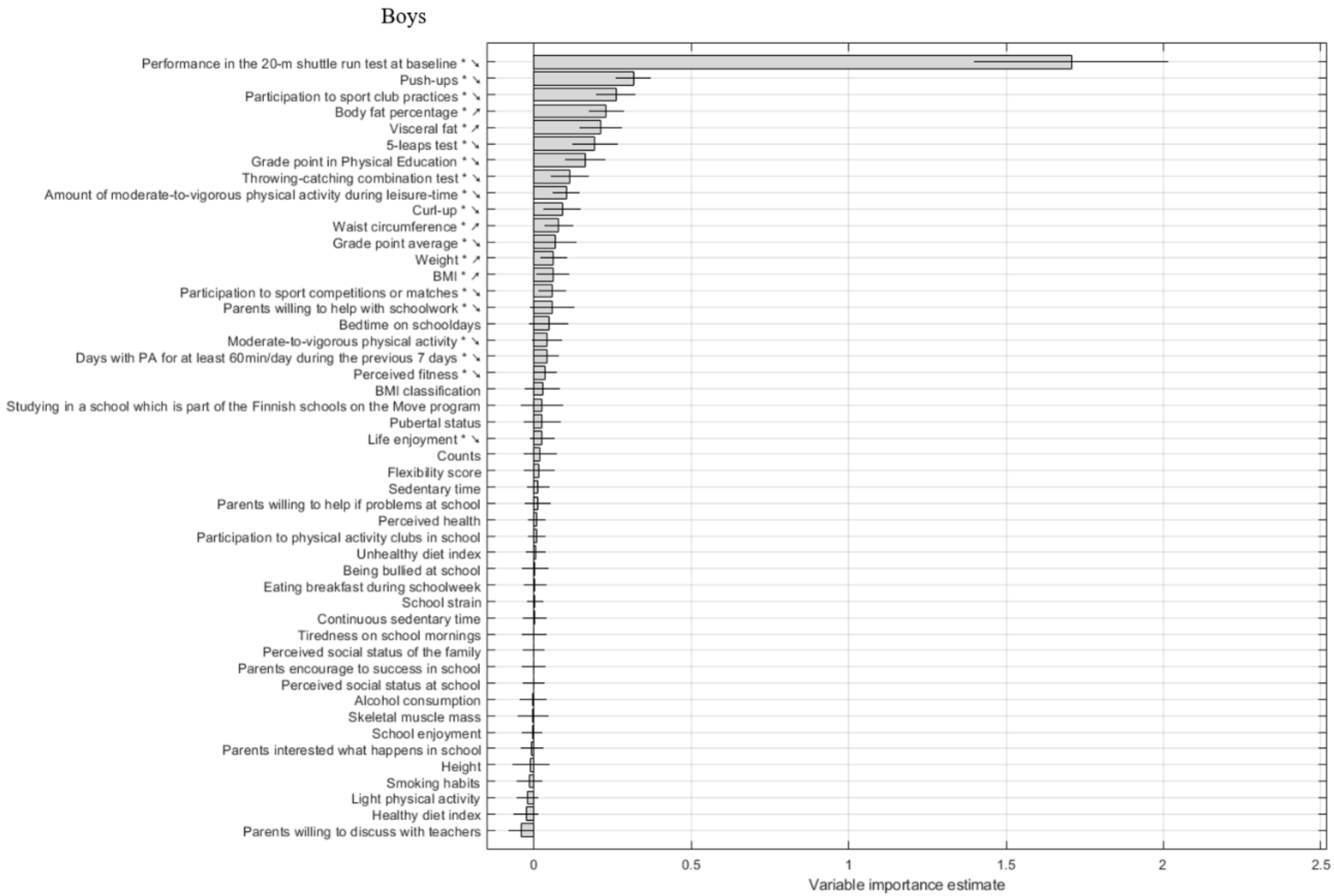

FIGURE 19. Best predictors for unfavourable 20-m shuttle run test prospects in boys. Statistically significant predictors are marked with * (P<0.05), and the direction of the association with arrows. The solid line represents the 95% confidence interval

5.4 Physical fitness, physical activity and self-rated health in adolescents

In study IV, the cross-sectional and longitudinal associations between a physical fitness index (a z-score average of 20-m shuttle run test, push-up, curl-up, 5-leaps test, throwing-catching combination test, and flexibility score), accelerometer-based MVPA, self-reported physical activity and self-rated health were assessed.

5.4.1 Cross-sectional associations

The cross-sectional part of the cross-lagged path analysis showed favourable associations between a higher physical fitness index and higher self-rated health in boys (standardised coefficient 0.282–0.283, P=0.002, in models with either accelerometery-based MVPA or self-reported physical activity), and a borderline association (0.161–0.162, P=0.051) in girls, independent of physical activity (accelerometery-based MVPA or self-reported), body fat percentage, and pubertal status (Figures 20 and 21). No statistically significant cross-sectional associations were observed between accelerometer-based MVPA and self-rated health. Higher self-reported physical activity levels were associated with higher self-rated health in both sexes (0.213, P=0.006 girls, 0.221, P=0.021 boys).

5.4.2 Longitudinal associations

Physical fitness showed no longitudinal associations with self-rated health in girls or boys when using either the physical fitness index (Figures 20 and 21) or when each of the fitness characteristic was analysed separately (additional information in the original manuscript (Study IV)).

Accelerometer-based MVPA showed no longitudinal associations with self-rated health in girls or boys when adjusting with the physical fitness index. However, in the analyses where each fitness characteristic was used in the model separately as the covariate, higher baseline accelerometer-based MVPA was consistently associated with better self-rated health at follow-up in boys. However, in girls, some of these similar associations were adverse, indicating that higher 5-leaps test or curl-up performance at baseline explained a lower self-rated health at follow-up (additional information in the original manuscript (Study IV)). Higher self-reported physical activity had positive longitudinal associations with self-rated health in boys (0.289, p=0.003) but not in girls (Figures 20 and 21).

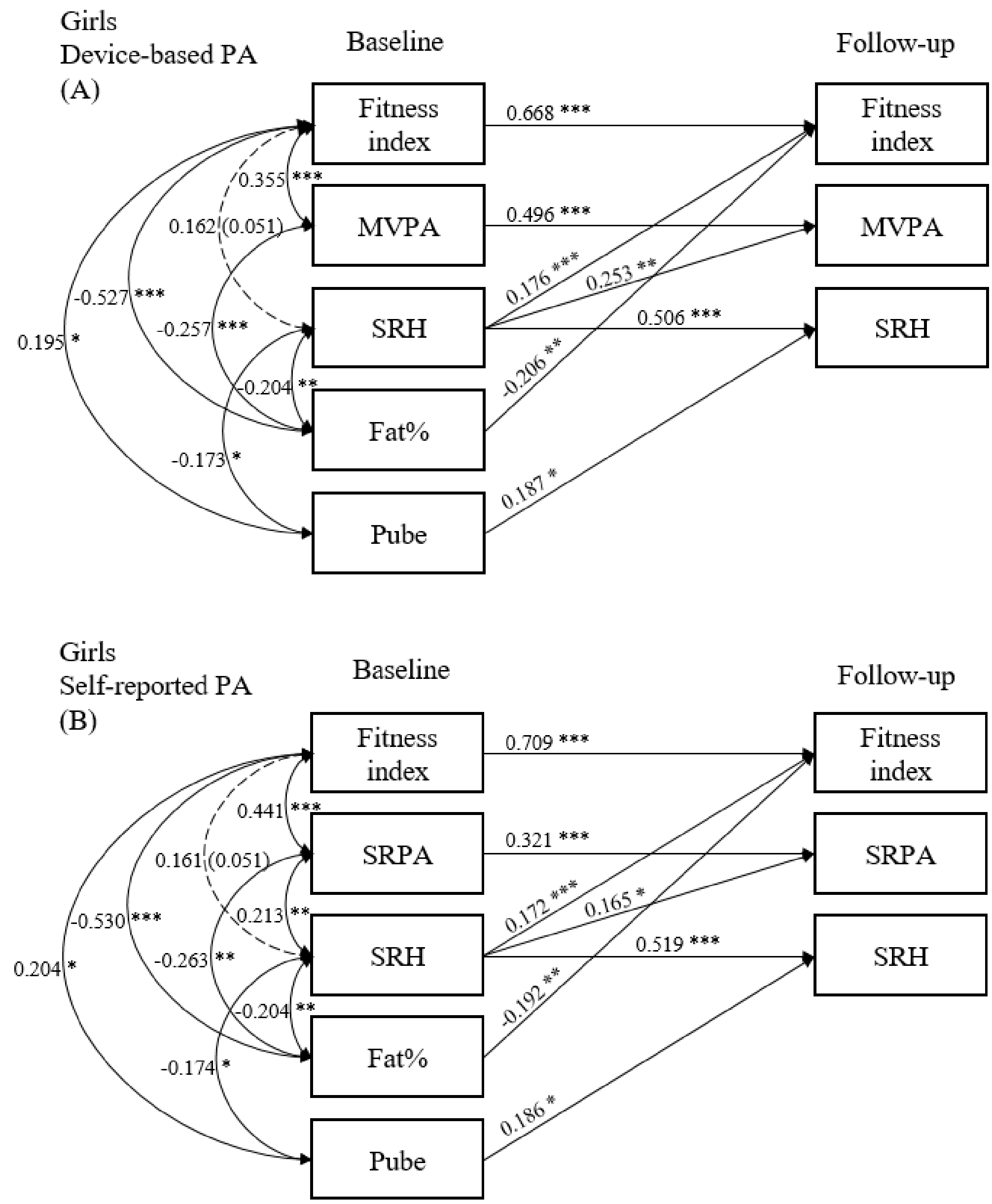

FIGURE 20. Cross-lagged path model showing cross-sectional and longitudinal associations of accelerometery-based moderate-to-vigorous physical activity (MVPA) (A) or self-reported PA (SRPA) (B) and physical fitness index (z-score average of Move! measurements), with self-rated health (SRH), independent of body fat % (Fat%) and pubertal status (Pube) in girls. * P≤0.05, **P≤0.01, ***P≤0.001

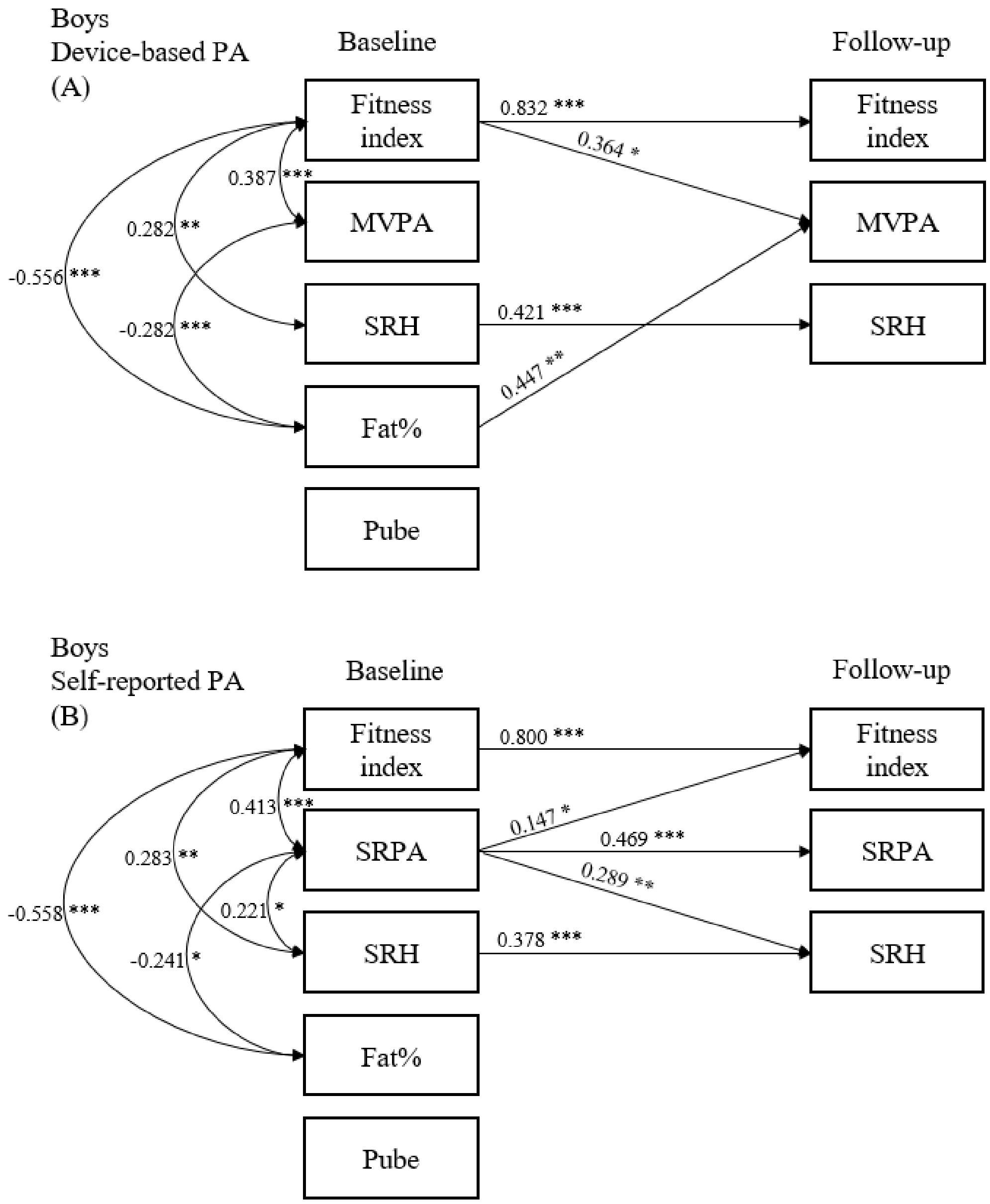

FIGURE 21. Cross-lagged path model showing cross-sectional and longitudinal associations of accelerometery-based moderate-to-vigorous physical activity (MVPA) (A) or self-reported PA (SRPA) (B) and physical fitness index (z-score average of Move! measurements), with self-rated health (SRH), independent of body fat % (Fat%) and pubertal status (Pube) in boys. * P≤0.05, **P≤0.01, ***P≤0.001

6 DISCUSSION

6.1 Main findings

Study I explored the cross-sectional associations of body composition and physical activity with physical fitness in adolescents. Adiposity had a strong negative association with physical fitness, while muscle mass and MVPA had positive associations with fitness. No association was observed between sedentary time and physical fitness. Body composition and physical activity explained 20-m shuttle run, push-up, curl-up and 5-leaps test scores on a practical level. For example, it was estimated that if a participant who was 155 cm tall would have five kilograms more fat mass, their 20-m shuttle run test result would be 8 laps (one stage) weaker. Five kilograms more fat-free mass and a 10-minute increment in daily MVPA were estimated to correspond to 2–6 laps better test results in 20-m shuttle run.

Study II showed that an increase in fat mass during adolescence attenuated coherently development in physical fitness characteristics. This inverse association was observed in both sexes and in all explored fitness characteristics, except for one, muscular fitness development measured with push-up in girls. Other examined factors had additional but not systematic associations with fitness development. The findings from Studies I and II indicate that adiposity had the strongest association with both physical fitness status and development during adolescence from the explored variables.

Studies II and III indicated that poor fitness tends to be tracked during adolescence in a group and at an individual level. Study III, as a novel finding, showed that adding to fitness-related characteristics and behaviour, additional factors predicted future cardiorespiratory fitness, such as academic performance, parents' willingness to help with schoolwork and life enjoyment. We utilised a machine learning approach in the prediction and found that 14 to 20 baseline characteristics had predictive power. Based on our findings, we believe that identification of the potential individuals for exercise and/or life-style interventions could benefit from machine learning-enabled holistic models. We furthermore provided a framework and open-source algorithms for future research.

Study IV showed, however, that although physical fitness was cross-sectionally associated with an indicator of overall health, i.e., self-rated health in adolescents, we found no longitudinal association between physical fitness and self-rated health. Instead, self-reported physical activity had more coherent associations with self-rated health than physical fitness.

6.2 Correlates of physical fitness in adolescents

When assessing the correlates of physical fitness, adiposity showed the most systematic associations. There was some variation, however, in the associations depending on sex and the fitness characteristic. For example, fat-free mass had the strongest association with curl-up in boys and with throwing-catching combination test in girls. MVPA had the strongest association with the throwing-catching combination test in boys. These differences are most likely explained by the specific features of the fitness measurements and the specialties related to the study sample.

The enhanced role of muscle mass in curl-up, i.e. muscular fitness, is logical. However, the findings from the other measurements assessing muscular fitness (push-up) did not support this finding (where adiposity was the strongest correlate in both sexes). This difference occurred because the push-up was more weight-bearing in nature compared to the curl-up.

Fat-free mass explained the strongest the results of throwing-catching combination test in girls. The observations during the data collection indicated that the girls struggled to throw the ball far enough during the test. These findings might indicate that although the test was designed to measure fundamental movement skills, especially in girls, muscle strength is an important explanatory factor. However, in boys, the strongest correlation with this task was with MVPA, probably because Finnish boys' leisure-time physical activity includes ball games more frequently than girls' (Aarnio et al. 2002). Majority of ball games are considered MVPA in adolescents (Ridley & Olds 2008); therefore, the higher MVPA status could explain better fundamental movement skills in boys. An interesting finding related to physical activity is that no associations were observed between sedentary time and physical fitness in adolescents. We want to acknowledge that although this finding is supported by previous studies (Cliff et al. 2016) there is evidence that high sedentary time is associated with deleterious health outcomes in adults (Biswas et al. 2015); therefore, the adverse long-term effects of excessive sedentariness should not be ignored.

Out of the variables used in our study, only adiposity was associated with flexibility. Our linear regression model could detect only 6.1% of the variance in flexibility in boys and 5.1% in girls, leaving 93.9% and 94.9% of the variance unexplained. This finding indicates that the Move! flexibility measurements have correlates other than those covered in this study. Previous knowledge supports this finding, remarking that flexibility is a specific characteristic in the physical fitness domain (Plowman 2014).

6.2.1 Why is adiposity so strongly associated with physical fitness?

Although adiposity tissue does not participate in moving the body in theory, why is adiposity so strongly associated with field-based physical fitness? This phenomenon requires further explanation. The origins of this phenomenon extent to vary basic laws of physics and gravity. Performance illustrates the ability to produce movement relative to body mass that is affected by gravity. While the part of the body mass that contributes to movement is beneficial for performance (e.g., fat-free mass, including muscle tissue and nerves), the part of the body mass that is not required to produce movement or to maintain essential bodily functions attenuates performance (e.g., excess adiposity). An example of how basic physics is associated with performance is Newton's second law of motion, $F = ma$, where force is equal to mass times acceleration. Acceleration is therefore $a = F / m$, i.e., force relative to mass. These laws of mechanics properly explain, for example, how, in the 20-m shuttle run test, a participant with larger fat mass has higher requirements for force production when accelerating their running speed during the test (Frost et al. 2010). Therefore, the test is more strenuous for those individuals with excess adiposity, resulting in a lower performance level.

This explanation is supported by the seminal work of Kirk Cureton and colleagues (1977) with children and adolescents. Cureton found that the main determinants for 600 yards and a one-mile run were the dash time 50 yards and body fat percentage. This hypothesis was further tested with added weight experiments (Cureton et al. 1978). In a small group ($n = 6$), it was noticed that added external weight to the trunk systematically and significantly decreased VO_2 max relative to total mass (body mass + added weight), maximal treadmill run time and distance in the 12-m run. However, added weight did not alter VO_2 max $L \cdot min^{-1}$ or $mL \cdot FFM^{-1} \cdot min^{-1}$. The authors concluded that 'changes in excess body weight can influence VO_2 max expressed relative to body weight and distance run performance independent of any change in cardiovascular capacity.' Fogelholm et al. (2008) also discussed why obesity impairs performance in fitness tests and highlighted that adiposity acts as an inert load during exercise. Therefore, it is important to understand how excess adiposity attenuates our ability to perform weight-bearing physical activities, and this phenomenon applies due to gravity.

6.2.2 Insights for interpreting the Move! measurements

In this study, we explored not only the statistically significant but also practically relevant associations between body composition, physical activity and physical fitness. Analyses showed that fat mass, fat-free mass and MVPA explained in a practical level only 20-m shuttle run test, push-up, curl-up and 5-leaps test scores.

These findings provide practical information for the end users of the Move! – monitoring system for physical functional capacity about the factors associated with the results.

Field-based measurements are developed to provide more feasible quantification of physical fitness compared to laboratory measurements. One of the main insights that unfolded during this study entity is that there is some observable sway in literature how physical fitness is described. Thomas Cureton (1945), one of the fathers of physical fitness research, introduced it "as ability to handle the body well and the capacity to work hard over a long period of time without diminished efficiency". Cureton characterized physical fitness via physique (e.g. healthy and robust appearance), organic capacity (e.g. fit heart and circulatory system), and motor fitness (e.g. at least average capacity in a wide variety of fundamental motor abilities – described at that time as motor skills, strength, endurance and flexibility). This concept has stood the test of time, as currently in literature physical fitness is still characterized via performance, physiological capacities, anthropometrics, and tissue structures.

Physical fitness can be considered to be a latent variable, something that is not directly observable, consisting of different subcomponents. One explanation for why physical fitness is still defined with varying wording could be that our perception of what physical fitness is varies. Physical fitness is by dictionary the body's condition of being fit, suitable or appropriate. However, no clear answer is available for what is considered to be a suitable condition of the body. Physical fitness has therefore presumably established different meanings in different contexts. Normative evaluation against a selected reference group has been used to estimate if one's fitness is adequate. Criterion-referenced approach is typically used to estimate if physical fitness is adequate from health perspective.

Commonly, the debate related to physical fitness revolves around if field-based tests can be used as a surrogate measure of laboratory measured golden standards. For example, in our ongoing systematic review (PROSPERO ID CRD42021236637), we have already identified over 40 articles assessing the validity of the 20-m shuttle run test. However, this academic discussion could potentially benefit from elevating the focus towards the construct of physical fitness, its umbrella concepts, and subcomponents, and reaching a consensus over selected terminology and methodology. The flexible use of current fitness metrics (mainly between performance and physiological capacities) complicates the comprehension of scientific findings and understanding the associations that physical fitness has for example with health.

The interpretation made in this thesis is that the Move! measurements assess the ability to perform different physically demanding tasks. Related theories are scarce, but in 2015, a holistic applicable model of the determinants of sports performance was published (Bangsbo 2015). In this theory, the different components related to performance are described—various physiological attributes extending from blood volume haemoglobin to motor unit recruitment, accompanied by psychological, technical, tactical and external factors (Figure 22).

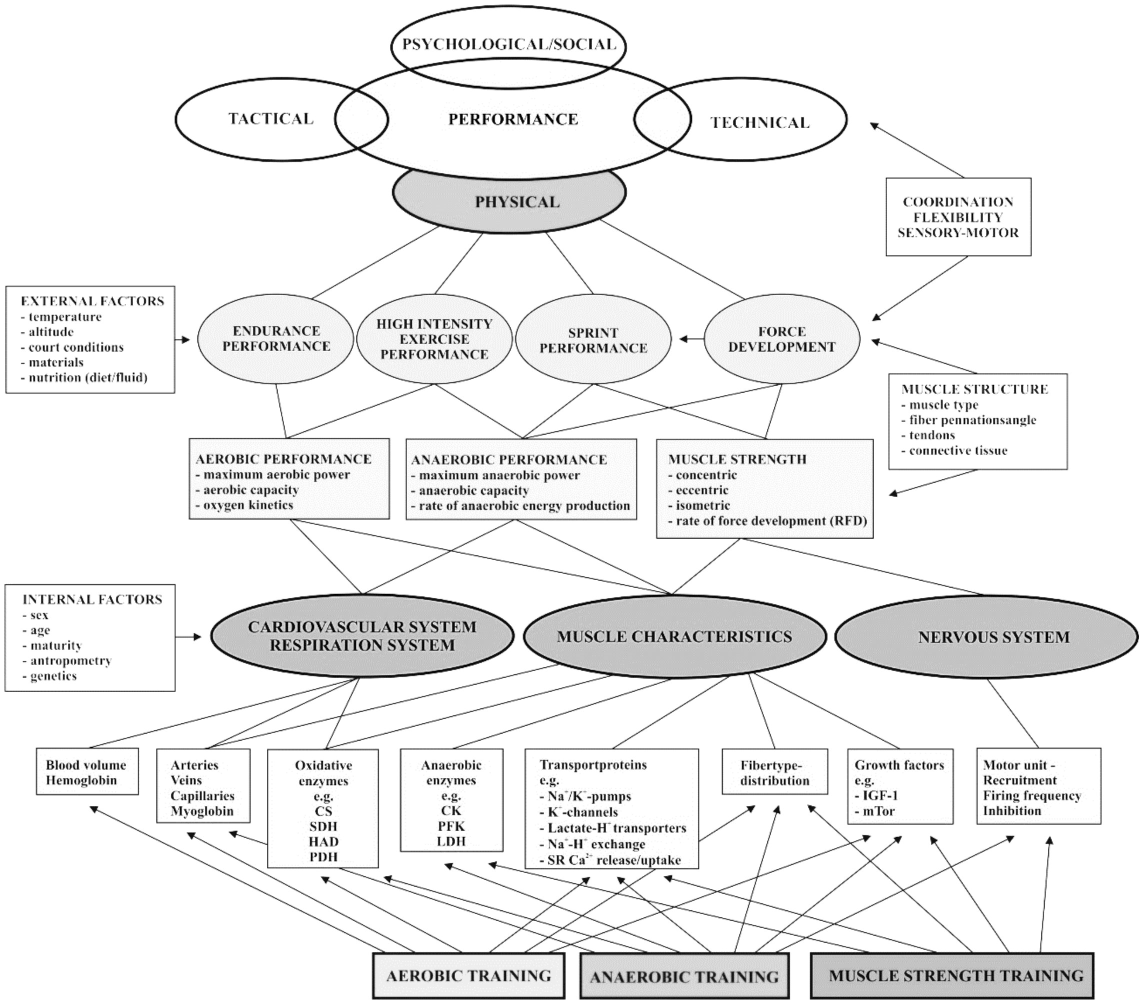

FIGURE 22. A holistic model of the determinants of sports performance. Reproduced with permission from Bangsbo (2015)

This theory illustrates the relationship between performance, physiological capacities and tissue structures. Based on this theory, observably, although different physical attributes can be measured separately, and even during performance, performance is the umbrella concept with various underlying subcomponents. The discussion of how fitness could be understood is not novel (Kemper & Van Mechelen 1996), but a timely topic, as monitoring physical fitness in school-aged children has grown in popularity recently, and understanding the monitored phenomena is imperative.

When selecting a physical fitness measurement for a given purpose, an important question is to ask what one wants to measure and why? Performance capacity is an important platform for daily function. Here, normative references are reasonable to apply, as the ability to participate in daily physical activities, such as play and games, is relative to the ability of peers. One main aim of the Move! – monitoring system for physical functional capacity is to support student's daily ability to perform and participate in physically demanding tasks. The prerequisites for these tasks are measured by the ability to run, jump, elevate the body, throw and catch objects, and have a sufficient range of motion in the body. The use of field-based performance measurements for similar aims seems justified. However, it is important to understand that weight-bearing measurements are considerably confounded by adiposity, and caution is needed, e.g. when evaluating the associations with health.

6.3 Physical fitness development during adolescence

Relations of body composition, physical activity and maturity with fitness development have been previously studied in adolescents. However, in previous research, these associations have been assessed mainly separately, leaving a research gap for studies analysing these associations collectively. This information is relevant, as the processes of biological growth and behavioural development are rather simultaneous and not separate in the adolescents' lives (Malina 2014). Furthermore, fitness development during adolescence in individuals with low fitness is underexplored. Evaluation of these factors is important to understand the development of adequate physical fitness.

Previous studies have found mixed findings and shown that BMI did not explain physical fitness development during 2 years in German school-children (Augste et al. 2015), but changes in BMI had an inverse association with fitness development in a 3 year follow-up study in adolescents (Aires et al. 2010). Our study adds to this current body of knowledge and demonstrates that associations for fat and fat-free mass are separate for fitness development. Previous studies have also utilised self-reported physical activity and found favourable associations with fitness development (Aires et al. 2010; Augste et al. 2015). This study adds to previous knowledge and describes the associations for device-measured physical activity. Although the findings of our study did not indicate systematic associations between changes in MVPA and fitness development, previous data from randomised controlled trials have consistently shown that different types of exercise programmes, especially at a high-intensity level, improve physical fitness (Ortega et al. 2008). Notably, our study used data from a longitudinal observational study. A broad interpretation of these findings might indicate that during adolescence, the natural changes in physical activity are not significant enough to enhance physical fitness development, at least in both genders and among several fitness characteristics. Therefore, exercise interventions are recommended to achieve desirable changes in physical fitness.

The main finding of our study was that excessive fat mass accrual significantly attenuated PF development. These findings further emphasise that physical fitness, measured with weight-bearing field tests, is strongly associated with adiposity and highlights the importance of preventing excessive fat accumulation during adolescence. Supporting healthy weight gain during growth and maturation can decrease functional capacity deficits. This theory is supported by evidence from secular trends where the decline in cardiorespiratory fitness (measured with running performance) follows the increase in international obesity trends (NCD Risk Factor Collaboration 2017; Führer et al. 2021). However, the secular changes in other fitness characteristics show smaller, and not consistent changes with obesity trends, e.g., muscle strength, and speed have slightly increased in children and adolescents during the past decades (Führer et al. 2021). It is acknowledged, that the degree of obesity manifests itself differently with different fitness characteristics, showing more stronger associations with cardiorespiratory fitness than with other fitness characteristics (Tomkinson et al. 2006). Moreover, the findings are not consistent in all populations, e.g., a study by Ndabi et al. (2019) showed that urban Tanzanian children and adolescents perform poorer in the 20-m shuttle run test compared to their English counterparts, despite their lower BMI and the evidence from previous studies showing more favourable cardiorespiratory fitness in sub-Saharan adolescent populations. This finding indicates that the associations also vary between populations and depend on the specific phenotype (Ndabi et al. 2019). Therefore, it is favourable to acknowledge that the associations between the degree of obesity and physical fitness are more refined than able to be studied in this thesis.

What are the novel findings related to PF development?

Study II evaluated physical fitness development in low fit adolescents. Special interest was directed to this group due to the higher potential for functional capacity deficiency in the future. We found that physical fitness developed in this group, like the normal population. However, physical fitness remained at a significantly lower level throughout the 2-year observation period in the low fit group compared to the normal population. This phenomenon was detectable in all fitness characteristics and in both sexes. These novel findings imply that low physical fitness sustains during adolescence and indicate importance to direct preventive measures to low fit individuals already before adolescence.

One of the novel findings of this study was that the development in physical fitness was more difficult to explain than the baseline status. The cross-sectional model could explain 48% and 40%, 46% and 40%, 71% and 58% of the variance in baseline cardiorespiratory, muscular fitness, and fundamental movement skills in boys and girls, respectively. The explanation rates for fitness development were 20% and 24%, 28% and 13%, 46% and 36% for the change in cardiorespiratory, muscular fitness, and fundamental movement skills in boys and girls, respectively. This means that the same variables could explain only half as much of the fitness development compared with the cross-sectional status. Some support for this finding is found in a previous study (Augste et al. 2015). A few explanations for this phenomenon were considered: 1) the phenotype is reasonably stable already during adolescence, 2) physical fitness development is confounded by the regression to the mean phenomena, 3) physical fitness development during adolescence is associated with other/additional factors not covered in this study (more information in the original manuscript (Study II)).

Study III aimed to predict future unfavourable cardiorespiratory fitness status and development in adolescents. In this study, we changed our focus to assess physical fitness development on an individual level and utilised a data-driven machine learning approach to select the best predictors of future cardiorespiratory fitness. The data included different baseline variables with physical, psychological and social indicators. The novel findings were that it was possible to predict unfavourable future cardiorespiratory fitness with the machine-learning approach in girls and boys. Machine learning algorithm identified 14–20 baseline characteristics associated with future cardiorespiratory fitness. These variables included low physical fitness, low perceived fitness, high markers of adiposity, low markers of physical activity, low academic achievement in school, low grade in physical education, low life enjoyment, low parental support and low perceived social status at school. These findings indicate that multiple factors, i.e. adolescent's overall physical, psychological and social wellbeing, contribute to the trajectory of the 20-m shuttle run test during adolescence. This information adds to the previous body of research, where cardiorespiratory fitness development is typically examined through growth and maturation ignited morphological changes (Armstrong & McManus 2017). Our findings indicate that information from the adolescent's overall physical, psychological and social status provides additional value over evaluating only an individual's physical fitness test score. These promising findings support the adoption of a more holistic approach when evaluating the results of physical fitness tests at an individual level. Potential use-cases are, for example, the national or regional fitness monitoring systems where up to > 90% of age-cohort are tested. Resources for interventions are typically limited and with more accurate methods are able to be directed for correct individuals.

These findings also show the potential of the machine learning approach in identifying potential individuals for interventions. In machine learning, patterns are explored from the data. This has benefits, as data-driven characteristic profiles, i.e. phenotypes, can be recognised. Furthermore, the cross-validation technique helps to overcome a common limitation of traditional statistics where models or thresholds tend to fit poorly with future individual-level observations (Shmueli & Koppius 2011). More robust identification methods are required for adolescents, as limited evidence is related to the physical fitness related criterion references. Robust evidence is recommended to avoid over-diagnostics and to assign reasonable measures for correct individuals.

6.4 Physical fitness, physical activity and self-rated health in adolescents

A simple single-item self-rating of health gives a powerful summary of an individual's overall health status (Fayers & Sprangers 2002). Cross-sectional findings have shown low levels of cardiorespiratory (Padilla-Moledo et al. 2012; Kantomaa et al. 2015) and muscular fitness (Padilla-Moledo et al. 2012) to be associated with poorer self-rated health in adolescents. There is a research gap in longitudinal associations between fitness characteristics and self-rated health. Two studies recently explored these associations with contradictory findings. Hanssen-Doose et al. (2020) reported muscular strength and coordination, but not cardiorespiratory fitness, to explain future self-rated health. However, a study by Padilla-Moledo et al. (2020) found cardiorespiratory fitness and a multicomposite fitness index to have longitudinal associations with self-rated health, but no associations were found with muscular strength. Therefore, the aim of Study IV was to clarify which fitness components are related to future self-rated health and to examine whether this association persists after adjusting for physical activity.

In contrast to previous findings, no longitudinal associations were found between a physical fitness index of the separate fitness characteristics and self-rated health during 2-year follow-up. However, reciprocal associations emerged in which self-rated health at the baseline explained future fitness index and physical activity in girls. Self-reported physical activity showed a more coherent favourable association with self-rated health than physical fitness or MVPA. The findings of our study provide novel information about the nature of longitudinal associations between physical activity and self-rated health and how they might be dependent on sex and the indicators used. The authors are not aware of studies comparing associations between accelerometery-based MVPA and self-reported physical activity with self-rated health in adolescents. Previously, Niemelä et al. (2019) showed in a cross-sectional study that the dose-response association between self-reported physical activity and self-rated health was stronger than with device-based physical activity and self-rated health in middle-aged men and women (Niemelä et al. 2019). Our study agreed with this finding and showed more favourable and stronger associations between self-reported physical activity and self-rated health than between accelerometer-based MVPA and self-rated health.

Our study was limited by the low number of participants with fair or poor self-rated health. Our study indicated that, in a relatively homogenous group of adolescents where the majority reported having good or excellent self-rated health, physical fitness characteristics did not favourably explain future self-rated health, but physical activity did at least in boys. These findings remind us that despite the previous evidence related to the phenomena, it is valuable to evaluate the phenomena in a representative sample, as these associations might differ in different populations. Additionally, the evidence favoured the utilisation of physical activity over physical fitness to better explain future self-rated health. The basis of physical fitness monitoring systems is ongoing systematic research (Safrit 1990). It is worth considering and evaluating which metrics are most valuable to monitor for specific purposes.

Despite its simple and feasible nature, self-rated health is an important marker of health, as it measures such a construct of health that is unachievable by clinical markers. Decreased self-rated health in adolescents can be considered an early indicator of unhealthy behaviour and/or circumstances even in the absence of current health consequences (Piko & Keresztes 2007). It resembles the World Health Organisation's definition of health: 'Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity.' The sensitivity analyses of Study IV supported this theory and showed that self-rated health was associated with health-related symptoms and behaviour. In boys, a fair or poor rating of self-rated health was associated with more frequent alcohol consumption. Additionally, very good self-rated health was associated with a lower prevalence of weekly headache and sleep disturbances in boys and girls, and weekly neck and shoulder pain, abdominal pain, and insomnia in girls (more information in the original manuscript (Study IV)). With strong stability during growth and maturation (Boardman 2006), tracking from adolescence to adulthood (Vie et al. 2014) and associations with morbidity and mortality in adulthood (Heistaro et al. 2001; Latham & Peek 2013), self-rated health is an important marker of health with the potential to be utilised more systematically in adolescents.

6.5 Methodological considerations

The major strengths of this study are the longitudinal study design, device-based assessments of physical activity, sedentary time, body composition and evaluation of various physical fitness components in a large sample of children and adolescents. BMI is commonly used in studies with large participant samples as a surrogate measure of adiposity, accompanied with subjective measures of physical activity and sedentary time. The strengths of this study include the extensiveness of the variables collected in the data sample and the novel and robust analyses.

This study used observational data. Despite these efforts, sampling bias might exist and could affect the generalisability of the findings to the general adolescent population. Utilising repeated measurements in the same study population might not indicate true development trajectory due to the learning effect. Limitations also include the 2-year duration of the study, where more prominent changes could have emerged with a longer follow-up period. Especially accelerometer measurements suffered from drop-out: 46.5% of the participants had information from T1 and T2 measurement points, and 29.3% from T1 and T3. Furthermore, more accurate data could have been obtained with 24-h registration. MVPA was characterised based on a one-week measurement and may not describe the whole year's physical activity behaviour or the activity status from previous years. Although accelerometers are commonly used to detect objective intensity and duration of physical activity, they do not record all types of physical activity (e.g., bike riding) or the quality of the activity (cardiorespiratory, musculoskeletal or neuromotor exercise).

The selected variables (physical activity, sedentary time and body composition) explained 5–68% of the variance in physical fitness in children and adolescents in Study I, leaving an additional 32–95% of the variance unexplained. This portion of the variance might include participant motivation, amount of practice, testing conditions and equipment, tester errors, and differences in running economy and heritage (Plowman & Meredith 2013, 9-4), which were not addressed in this study. Flexibility showed poor associations in the baseline with the variables utilised in this study; therefore, the discussion related to flexibility is limited.

7 FUTURE PERSPECTIVES AND CONCLUSIONS

7.1 Practical implications

Adolescence is an important timeframe related to physical fitness, as fitness attributes tend to peak or attain the highest proportion of development during adolescence. Physical fitness status during adolescence is meaningful to later life and the time when the poor fitness disability threshold is met. Potential societal benefits emerge if a sufficient number of people can be helped to reach a sustainable level of physical fitness at the beginning of their life course. Without data, it is difficult to follow population-level changes in fitness or find individuals benefitting from interventions. These findings suggest a rationale for monitoring physical fitness during adolescence.

The prior critique of fitness monitoring has shown concerns that field-based physical fitness measurements are invalid surrogates for laboratory measured fitness characteristics. The findings of this study entity raise the question that instead of comparing field-based and laboratory-measured physical fitness, could field-based fitness measurements represent a different construct, i.e. one's abilities to perform and participate in physically demanding activities. Previous critique has also specified that physical fitness monitoring should be replaced or at least reinforced with measurements that are more closely associated with health, e.g. with physical activity assessments. This study entity found that self-reported physical activity was more coherently associated with self-rated health than physical fitness. However, notably, the rationale for fitness monitoring varies. In an EU-funded collaboration project, FitBack, where countries with operating national monitoring systems produced tips and instructions on how to design and build a monitoring system, the first step was highlighted as 'set up mission statement and aims.' This guideline refers to the fact that the aims of the monitoring systems differ in different societies, and the mission and aims give each monitoring system their own the framework. If the aim of the system is to monitor the status of functional capacity, the utilisation of field-based physical fitness measurements are reasonable. If the aim of the system is to prevent health risks, it is reasonable to assess which measurements have the strongest association with the desired outcome. However, in the future, a more phenotype-based approach is recommended that encompasses multiple variables. Critique has also been addressed that fitness testing is embarrassing for those with low physical fitness. This is an important remark, as low-fit individuals are typically the core focus of monitoring systems. When conducting fitness measurements in adolescents, it is important to acknowledge that participants might experience higher levels of anxiety during fitness testing compared to a regular physical education class and give additional focus to fostering their basic psychological needs (Huhtiniemi et al. 2021). Additionally, providing an educational context for physical fitness measurements administered in schools could enhance their educational value and psychosocial outcomes (Cohen et al. 2015). Furthermore, considering when a participant would benefit from the utilisation of adapted measurements is imperative.

How to support adequate PF attainment in adolescents?

The findings of this study suggest a few alternatives for promoting optimal natural physical fitness development during adolescence. First, we observed that poor fitness tends to be tracked during adolescence in a group and at an individual level. In practice, adolescents with low physical fitness are likely to have low physical fitness in the future without interventions. Therefore, it is recommended to focus on adolescents, but also already before adolescence to children. Previous findings provide few alternatives for how to enhance physical fitness status in children and adolescents at the population level.

First, conditions during the early phase of life have an important influence on later life. This is the case in all life forms, including animals and humans. Previous findings show that the earlier an individual's development is disturbed, the stronger are the effects. Research related to early development in birds and mammals gives a perspective and shows that the circumstances of early life greatly affect the dynamics of the future population (Lindström 1999). Previous human studies have shown that the socioeconomic status of the family during childhood is already associated with physical fitness in 3–5-year-old children (Merino-De Haro et al. 2019), with associations extending to adulthood (Poulton et al. 2002). Serious illnesses requiring rigorous treatments, such as childhood cancer, are associated with a decline in children's physical fitness, and cancer survivors show reduced levels of fitness even 10–20 years after treatments (van Brussel et al. 2005; Antwi et al. 2019; Yildiz Kabak et al. 2019). However, relatively short-term impairments, e.g. reduced mobility in paediatric patients with lower limb fractures, have reportedly no long-term effects (Rowland 1994; Ceroni et al. 2012).

There is also compelling evidence for a biologically regulated natural phase of physical activity, which provides the potential to apply population-level exercise interventions more easily for children compared to other phases of life.

Age-related decline in physical activity levels is a consistent observation with self-reported and device-measured physical activity, and in human and animal studies. The greatest decline in physical activity occurs during adolescence, and studies have shown the most drastic changes between 12 and 18 years (Sallis 2000). The concept of self-stimulated playful physical activity during childhood is observable throughout the animal kingdom and humankind. This playful physical activity is considered to reflect the biological stimulus required to support the development of the central nervous system—a biological need that attenuates with forthcoming maturity (Rowland 1998). Previous studies on Finnish children have shown that physical activity levels in children are associated with the opportunities provided by the parents, and children are more active if parents support and enable physical activity (Laukkanen et al. 2017). Therefore, there is a window of opportunity for physical activity available during childhood with potentially favourable long-term effects.

Second, maintaining a healthy weight during growth, maturation and development are essential for optimal physical fitness attainment. Research conducted in Finnish children has shown that health-related behaviours, i.e. nutrition, physical activity and sleep, are core pillars for healthy weight in children and adolescents. A study conducted with Finnish preschoolers showed that meeting sleep and physical activity guidelines supports healthy weight status in young children (Leppänen et al. 2019).

Third, it is important to acknowledge that not only adiposity, but also other factors affects physical fitness. If adiposity acts as an inert load, performance capacity can be enhanced by developing the systems responsible for producing movement. Children and adolescents are trainable across parameters of aerobic, muscular and neuromotor fitness (Faigenbaum & Rhordi 2017; McNarry & Armstrong 2017; Oliver & Rhrodri 2017). Some evidence exists that during adolescence, exercise provides additional gains in physical fitness. This theory is based on the anatomical development timeline and the favourable hormonal profile during puberty. However, some of these sensitive periods have shown little evidence when critically evaluated, and versatile exercise is recommended during growth and maturation without excessively emphasising specific windows of opportunity for physical fitness characteristics (Van Hooren & De Ste Croix 2020).

7.2 Future directions for research

This study entity revealed a few alternative approaches for future research. First, more fundamental work is required to reach consensus related to the terminologies, definitions and constructs related to physical fitness.

Second, field-based physical fitness measurements require further work related to their criterion references. Noteworthy, these references do not necessarily need to be health-related. Alternative approaches, such as adequate functional capacity, require consideration.

Third, the precision exercise medicine approach can replace the currently used criterion-reference methods. These data-driven models based on participants' phenotypes can overcome problems related to low individual-level discrimination accuracy and fragmented information.

7.3 Conclusions

This study entity showed that excess adiposity is strongly associated with unfavourable physical fitness and development (I, II). Future cardiorespiratory fitness can be predicted based on adolescent's holistic profile (III), and physical activity but not physical fitness explains future self-rated health (IV).

Epidemiological data show that, in a normal population, physical fitness attributes tend to peak or gain the highest proportion of development naturally during adolescence. Physical fitness measured with weight-bearing assessments reflects an individual's ability to perform physically demanding tasks. Physical fitness attainment during adolescence is meaningful for future life, enables participation in various activities, and postpones the time when the life-limiting disability threshold is met.

Low fitness levels tend to sustain during adolescence. These findings indicate the importance of being aware of the individual's physical fitness status, monitoring fitness development, and targeting measures for adolescents, but also for children as well. Physical fitness attainment can be supported by monitoring and promoting healthy weight gain during growth and maturation. Exercise interventions are recommended for children and adolescents with low physical fitness status. Physical fitness characteristics are trainable in this age-group. The identification methods of potential individuals for interventions should be further developed. Physical fitness did not explain future self-reported health in this study sample, but physical activity did, and most coherent favourable associations were observed with self-reported physical activity. It is therefore important to evaluate which variables are truly the best predictors for the desired outcome and carefully decide what attributes are reasonable to monitor. Phenotype-based holistic models provide a reasonable alternative to currently used criterion references.

YHTEENVETO (SUMMARY IN FINNISH)

Valtakunnallinen Move!-järjestelmä ja väitöskirjatutkimus

Move! on fyysisen toimintakyvyn valtakunnallinen tiedonkeruu- ja palautejärjestelmä, jonka keskeisenä tarkoituksena on kannustaa lapsia ja nuoria omatoimiseen fyysisestä toimintakyvystä huolehtimiseen. Järjestelmä käynnistettiin Suomessa vuonna 2016 peruskoulujen liikunnanopetukseen integroituna. Move!-järjestelmässä viidennen ja kahdeksannen luokan oppilaat osallistuvat koulupäivän aikana mittauksiin, joissa arvioidaan kestävyyskuntoa, lihaskuntoa, motorisia taitoja ja liikkuvuutta. Mittausten tietoa voidaan hyödyntää yksilötasolla liikunnanopetuksessa sekä oppilaan laajassa terveystarkastuksessa täydentämään kuvaa kasvusta, kehityksestä, kypsymisestä sekä terveydentilasta. Lisäksi saadaan yhteiskunnallisesti merkityksellistä tietoa lasten ja nuorten fyysisen toimintakyvyn alueellisesta ja kansallisesta tilasta sekä ajallisista muutoksista, joilla voidaan ennakoida mahdollisia väestön toimintakykyyn ja terveyteen liittyviä haasteita (Opetushallitus 2021).

Move!-järjestelmä tavoittaa vuosittain merkittävän määrän suomalaisia lapsia ja nuoria perheineen. Vuonna 2020 mittauksiin osallistui 104 899 oppilasta, eli yli 90 % ikäluokasta. Move!-järjestelmä on kansainvälisesti ainutlaatuinen. Eurooppalaisessa vertailussa vain seitsemässä maassa on kansallinen fyysisen kunnon seurantajärjestelmä, joista Move! erottuu edukseen osallistumis-asteeltaan, mahdollisuudessa soveltaa mittauksia toimintakykyrajoitteiden mukaan sekä kiinteällä yhteydellään terveystarkastuksiin (The European Network for the Support of Development of Systems for Monitoring Physical Fitness of Children and Adolescents 2021).

Jotta Move!-järjestelmää voidaan hyödyntää kouluissa, terveydenhuollossa ja päätöksenteossa parhaalla mahdollisella tavalla, tueksi tarvitaan tutkimustietoa. Tämän väitöskirjakokonaisuuden tavoitteena oli lisätä ymmärrystä Move!-mittausten tulkintaan liittyen. Tässä yhteenvedossa kuvataan väitöskirjan neljään tieteelliseen osatyöhön sekä tuoreimpaan kansainväliseen tutkimustietoon perustuen, mitä Move!-mittausten tulkinnasta tällä hetkellä tiedetään.

Väitöskirjatutkimuksessa hyödynnettiin Likesin Oppilaiden liikunta ja hyvinvointi -seurantatutkimuksen aineistoa vuosilta 2013–2015. Tutkimukseen osallistui 970 nuorta (12,6 ± 1,3 vuotta, 52,4 % tyttöjä), jotka toteuttivat vuosittain Move!-mittaukset sekä kehonkoostumuksen, murrosiän vaiheen, liikunta-aktiivisuuden ja koetun terveyden mittaukset. Kehonkoostumusta arvioitiin bioimpedanssimenetelmällä, murrosiän vaihetta kyselyllä Tannerin asteikon avulla, fyysistä aktiivisuutta kiihtyvyysanturilla ja kyselyllä sekä koettua terveyttä kyselyllä. Analysointimenetelminä käytettiin regressio- ja rakenneyhtälömalleja sekä koneoppimisanalytiikkaa.

Move!-järjestelmän tavoitteena on arvioida oppilaan fyysistä toimintakykyä. Fyysinen toimintakyky on elimistön toiminnallinen kyky selviytyä fyysistä ponnistelua edellyttävistä tehtävistä ja sille asetetuista tavoitteista (Rissanen 1999, 31). Tässä ikäryhmässä tämä tarkoittaa esimerkiksi kykyä liikkua omin voimin, harrastaa ja huolehtia päivittäisistä toimista. Move!-järjestelmässä fyysistä toimintakykyä arvioidaan fyysisten kunto-ominaisuuksien kautta. Kouluissa toteutettaviin Move!-mittauksiin kuuluvat 20 metrin viivajuoksu (kestävyys-kunto), ylävartalonkohotus ja etunojapunnerrus (lihaskunto), kyykistys, alaselän ojennus täysistunnassa ja olkapäiden liikkuvuus (liikkuvuus) sekä vauhditon 5-loikka ja heitto-kiinniottoyhdistelmä (motoriset perustaidot).

Kyseiset mittaukset ovat ns. kenttätestejä, eli fyysisen kunnon määrällistä tutkimusta ilman laboratorio-olosuhteita. Tutkimusalalla on jo pitkään keskusteltu siitä, kuvaavatko kenttätestit riittävällä tarkkuudella samoja ominaisuuksia kuin laboratoriomittaukset. Taustalla keskustelua hämärtää osittain erilaiset käsitykset siitä, mitä fyysinen kunto itseasiassa on. Fyysisen kunnon määritelmä ei ole yksiselitteinen. Caspersenin ym. (1985) määritelmän mukaan fyysinen kunto on joukko ominaisuuksia, joita ihmisellä on tai joita hän on hankkinut, ja jotka ovat yhteydessä kykyyn toteuttaa fyysistä aktiivisuutta. Fyysisen kunnon voidaan ajatella olevan tutkimuskielellä latentti muuttuja, eli ei suoraan havaittavissa oleva asia, joka koostuu eri osa-alueista.

Näkemys siitä, mitä eri osa-alueita fyysiseen kuntoon sisällytetään, vaihtelee tutkimusaloittain. Caspersenin ym. (1985) määritelmän mukaan fyysinen kunto koostuu kestävyyskunnosta, lihasvoimasta ja -kestävyydestä, nopeudesta ja nopeusvoimasta, motorisista taidoista, liikkuvuudesta sekä kehonkoostumuksesta. Alan kirjallisuudessa näitä osa-alueita mitataan yleisesti suorituskyvyn, fysiologisten kapasiteettien tai kudosrakenteiden kautta. Joissakin kunnon osa-alueissa tämä voi aiheuttaa sekaannuksia, sillä esimerkiksi kestävyyskuntoa saatetaan kuvata yhtä lailla suorituskyvyn (esim. juostessa saavutettu matka tai nopeus) kuin suorituskyvyn alakäsitteiden, kuten fysiologisen kapasiteetin, avulla (esim. maksimaalinen hapenottokyky). Fyysiseen kuntoon liittyvien termien ja määrittelyjen yhtenäistäminen olisi tulevaisuudessa suotavaa, ja ylä- ja alakäsitteiden välinen jaottelu hyvä erottaa toisistaan, jotta pystytään lisäämään yhteistä ymmärrystä fyysisestä kunnosta sekä tulkitsemaan johdonmukaisemmin esimerkiksi fyysisen kunnon ja terveyden välisiä yhteyksiä.

Tähän taustaan pohjautuen tässä väitöskirjassa on tehty tulkinta, että Move!-mittaukset arvioivat suorituskykyä fyysisissä tehtävissä, joissa tarvitaan kestävyyttä, voimaa, motorisia taitoja ja liikkuvuutta. Yhdessä ne muodostavat kuvaa henkilön kokonaisvaltaisesta fyysisestä kunnosta. Hyvä fyysinen kunto on hyvää kyvykkyyttä tehdä erilaisia fyysisiä tehtäviä. Fyysinen kunto luo valmiudet arjen fyysiselle toimintakyvylle.

Suomen sanakirjan mukaan fyysinen kunto tarkoittaa ruumiillista kelpoisuutta, valmiutta, kyvykkyyttä ja hyvää tilaa (Kotimaisten kielten keskus 2021). Tähän määritelmään liittyy kiinteästi myös vertailu, jota yleisimmin tehdään normatiivisesti, eli vertaamalla ominaisuuden tasoa vertailujoukkoon. Move!-järjestelmässä tämä tapahtuu vertailemalla kunto-ominaisuuksien tilaa samanikäisiin saman sukupuolen edustajiin. Move!-järjestelmässä palautetta annetaan kolmiportaisesti: ominaisuus on keskimääräistä paremmalla tasolla, keskimääräinen tai keskimääräistä heikommalla tasolla ikätovereihin verrattuna. Poikkeuksen tekee liikkuvuus, joka on kahtiajakautuva muuttuja, eli mittaus on kriteerien mukaan joko onnistunut tai ei.

Tutkimuksessa selvitettiin, mitkä tekijät selittävät heikkoja Move!-mittausten tuloksia. Päätuloksina havaittiin, että runsas rasvan määrä kehossa oli yhteydessä heikompiin tuloksiin kaikissa mittausosioissa. Esimerkiksi nuorella, jolla oli viisi kiloa enemmän rasvaa kehossaan kuin samanpituisella ikätoverilla, oli laskennallisesti minuutin verran heikompi tulos 20 metrin viivajuoksussa (väitöskirjan osajulkaisu I). Fyysinen kunto kehittyy luontaisesti nuorilla iän myötä, mutta tutkimuksessa havaittiin, että runsas rasvan määrän lisääntyminen murrosiän aikana vaimensi fyysisen kunnon kehittymistä voimakkaasti (väitöskirjan osajulkaisu II).

Painovoima ja fysiikan lait vaikuttavat osaltaan siihen, että mitatessa fyysistä kuntoa kehonpainoa vasten tehtävillä suorituksilla liikettä tuottamaton rasvamassa toimii ylimääräisenä kuormana. Näin ollen runsaasti ylipainoisilla Move!-mittausten fyysiset tehtävät ovat raskaampia toteuttaa kuin normaalipainoisilla, ja he todennäköisesti saavat muita heikompia tuloksia. Arjessa toimimisen kannalta tämä kyky liikuttaa itseään on merkityksellistä. On kuitenkin myös hyvä huomioida, että rasvakudosta tarvitaan riittävästi tukemaan kehon tervettä toimintaa.

Kun tutkittiin sellaisen nuoren kokonaisvaltaista profiilia, jolle kehittyy heikko kestävyyskunto murrosiän aikana, havaittiin ylipainon lisäksi muita tunnistettavia piirteitä. Näillä nuorilla oli haasteita yleisessä elämäntilanteessa, eli fyysisessä, psyykkisessä ja sosiaalisessa hyvinvoinnissa, ja tarkemmin ottaen ylipainossa, Move!-mittauksissa, liikunta-aktiivisuudessa, koulumenestyksessä, sosiaalisissa suhteissa koulussa ja kotona sekä elämäntyytyväisyydessä (väitöskirjan osajulkaisu III). Tutkimuksessa havaittiin myös, että heikko fyysinen kunto oli melko pysyvä tila, eli niillä lapsilla ja nuorilla, joilla oli heikko fyysinen kunto kahden vuoden seurantatutkimuksen aluksi, oli todennäköisesti heikko fyysinen kunto myös seurannan päätteeksi. Erot fyysisessä kunnossa eivät siis kaventuneet murrosiän aikana (väitöskirjan osajulkaisu II; väitöskirjan osajulkaisu III).

Nämä havainnot antavat viitteitä siitä, että kehittämistoimenpiteitä kannattaa suunnata jo varhain niille, joilla havaitaan puutteita fyysisessä kunnossa. Keskeisiin toimenpiteisiin kuuluvat terveellisen painon ylläpitäminen kasvun ja kehityksen aikana sekä tätä tukevat elintavat jo lapsuudesta saakka. Jos lapsi tai nuori saa heikon tuloksen Move!-mittauksista, kannattaa häneltä aluksi kysyä miten mittaukset sujuivat. Heikkoon tulokseen voivat vaikuttaa fyysisen kunnon lisäksi muut tekijät, kuten motivaatio, olosuhteet ja mahdolliset poikkeavat tilanteet mittausten aikana. Toimenpiteiden kohdentamisessa voi Move!-mittaustulosten lisäksi hyödyntää kokonaisvaltaisen elämäntilanteen arviointia. Jos fyysisen kunnon kehittämiseen ilmenee tarvetta, on hyvä muistuttaa nuorta, että kaikki osa-alueet ovat harjoittelulla kehitettävissä.

Move! terveydentilan arvioinnissa

Move!-järjestelmä on kiinteästi yhteydessä laajoihin terveystarkastuksiin, ja fyysisellä kunnolla on aiemmissa tutkimuksissa havaittu olevan suotuisia yhteyksiä terveyteen. Näin ollen Move!-mittauksilla on merkittävää potentiaalia tuottaa lisäarvoa terveydenhuollolle. Tässä tutkimuksessa selvitettiin Move!-mittausten yhteyksiä koettuun terveyteen. Koettu terveys on lapsen tai nuoren arvio omasta terveydentilastaan neliportaisella asteikolla erittäin hyvästä huonoon. Koetun terveyden on havaittu lapsilla ja nuorilla ilmaisevan epäsuotuisia elintapoja ja olosuhteita sekä ennakoivan terveysriskejä jo ennen niiden ilmaantumista. Vaikka kansainvälisissä tutkimuksissa on aiemmin havaittu suotuisia yhteyksiä fyysisen kunnon osa-alueiden ja tulevan koetun terveyden välillä, vastaavaa yhteyttä ei voitu toistaa tässä tutkimuksessa. Kokonaisvaltaisen fyysisen kunnon tai Move!-mittausten eri osa-alueet eivät selittäneet tulevaa koettua terveyttä tutkimusjoukolla (väitöskirjan osajulkaisu IV).

Move!-mittausten ja terveyden välistä tutkimustietoa on vielä vähän. Tällä hetkellä vahvin näyttö tukee hyvän 20 metrin viivajuoksun tuloksen (kestävyyskunto) yhteyttä parempaan kudosrakenteeseen (kehonkoostumus, aivojen ja luuston rakenne), sydänterveyteen, aineenvaihduntaan, psykososiaaliseen hyvinvointiin sekä kognitiiviseen toimintaan lapsilla ja nuorilla. Erityisesti 20 metrin viivajuoksulle on kansainvälisissä tutkimuksissa pyritty kehittämään terveyskriteeriperusteista arviointia, eli raja-arvoja, jotka osoittaisivat terveyden kannalta riittävän kuntotason. Tällä hetkellä nämä raja-arvot eivät kuitenkaan riittävällä tarkkuudella erottele riskihenkilöitä muusta väestöstä. Todennäköistä onkin, että pelkästään fyysisten kunto-ominaisuuksien avulla tätä erottelua ei pystytä tekemään. Tulevaisuudessa on syytä kehittää menetelmiä, joissa hyödynnetään tietoa lapsen ja nuoren kokonaisvaltaisesta elämäntilanteesta.

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APPENDICES

Appendix 1. Description of selected variables utilized in the study

Selected variables	Range (continuous variables), scale (nominal and ordinal variables)	Unit	Notes	Measured
Background information				
Age	9.2–15.3	years	Decimal age (counted from date of birth)	S 2013
Sex	0, 1	boy = 0, girl = 1		S 2013
Studying in a school which is part of the Finnish schools on the Move program	0, 1	no = 0, yes = 1		S 2013
Data from objective measurements				
Accelerometer-based physical activity				
Sedentary time	40–86	%	Percentage of device wearing time	S 2013
Light physical activity	88–378	$min \cdot day^{-1}$	Weighted mean value	S 2013
Moderate-to-vigorous physical activity	9–163	$min \cdot day^{-1}$	Weighted mean value	S 2013
Continuous sedentary time	15–343	$min \cdot day^{-1}$	Weighted mean value of continuous sedentary time longer than 10min	S 2013
Counts	111–1211	$cpm \cdot day^{-1}$	Counts per minute per day. Weighted mean value	S 2013
Physical fitness				
Performance in the 20-m shuttle run test at baseline	3–109	laps	Laps run until voluntary exhaustion. Protocol by Finnish Move! – monitoring system for physical functional capacity (slightly	S 2013

			modified version from the EUROFIT protocol)	
5-leaps test	4.5−12.2	m	Distance measured in 0.1 m accuracy	S 2013
Push-ups	0−63	repetitions	Within 1-minute	S 2013
Curl-up	0−75	repetitions	Maximum of 75 repetitions	S 2013
Flexibility score	0−4	sum	Sum of four flexibility assessments	S 2013
Throwing-catching combination test	0−20	repetitions	Maximum of 20 repetitions	S 2013
Antropometrics and body compositon				
Height	131.3−184.9	cm	Stature measured in 0.1 cm accuracy	S 2013
Visceral Fat	5.0−223.7	cm^2	Estimation by bioelectric impedance	S 2013
Weight	24.3−102.8	kg	Measured in 0.1 kg accuracy	S 2013
Skeletal muscle mass	10.6−39.5	kg	Estimation by bioelectric impedance	S 2013
Body fat percentage	3.0−47.9	%	Estimation by bioelectric impedance	S 2013
BMI	12.8−36.3	$kg \cdot m^{-2}$		S 2013
Waist circumference	45.0−118.2	cm		S 2013
BMI classification	1−3	Normal weight = 1, overweight = 2, or obese = 3.	Classification by Cole scale	S 2013
Data from self-assessment questionnaires				
Pubertal status	0−5	pre-pubertal = 0, fully matured = 5.	Classification by Tanner scale. From pre-pubertal to fully matured.	S 2013
Perceived health	1−4	very good = 1, poor = 4	From very good to poor. ICC: 0.575	S 2013
Perceived fitness	1−4	very good = 1, poor = 4	From very good to poor. ICC: 0.678	S 2013
Days with physical activity for at least 60min/day during the previous 7 days	0−8	1 = 0 days, 8 = 7 days	From 0–7 days. ICC: 0.590	S 2013

		Amount of moderate-to-vigorous physical activity during leisure-time	0–6	1 = not at all, 6 = 7 hours or more	From 0 to ≥7 h/week. ICC: 0.752	S 2013
		Participation to physical activity clubs in schools	1–3	not at all = 1, regularly = 3	From not at all to regularly. ICC: 0.704	S 2013
		Participation to sport club practices	1–4	not at all = 1, regularly = 3	From not at all to regularly. ICC: 0.876	S 2013
		Participation to sport competitions or matches	1–5	not at all = 1, regularly = 3	From not at all to regularly. ICC: 0.865	S 2013
		Bedtime on schooldays	1–7	From 21:00 = 1, to 24:00 or later = 7	From 21:00 to 24:00 or later. Assessed with half hour intervals. ICC: 0.876	S 2013
		Tiredness on school mornings	1–4	never = 1, 4 times/week or more = 4	From never to 4 times/week or more. ICC: 0.679	S 2013
		Eating breakfast during school week	1–4	every day = 1, rarely = 4	From every day to rarely. ICC: 0.621	S 2013
		Smoking habits	1–5	not at all = 1, once a day or more = 5	From not at all to once a day or more.	F 2013
		Alcohol consumption	1–9	not at all = 1, every day = 9	From not at all to every day.	F 2013
		Unhealthy diet index	1–7	not at all = 1, more than once a day = 7	An index score for eating unhealthy foods from not at all to more than once a day (an average score of eating sweets or chocolate, sugary soft drinks, hamburgers or hot dogs, crisps, and pizza).	F 2013
		Healthy diet index	1–7	not at all = 1, more than once a day = 7	An index score for eating healthy foods from not at all to more than once a day (an average of eating fruits and vegetables).	F 2013

		School enjoyment	1−4	a lot = 1, not at all = 4	From a lot to not at all. ICC: 0.752	S 2013
		School strain	1−4	not at all =1, a lot = 4	From not at all to a lot. ICC: 0.608	S 2013
		Being bullied at school	1−5	not at all =1, several times a week = 5	Being bullied within a last couple of months from not at all, to several times a week. ICC: 0.428	S 2013
		Perceived social status in school	1−10	10 = 1, 1 = 10	A ladder scale: on the high end students who are appreciated most (10, coded as 1). At low end students who nobody appreciates (1, coded as 10). ICC: 0.779	S 2013
		Perceived societal status of the family	1−10	10 = 1, 1 = 10	A ladder scale: on the high end people who most people appreciate (10, coded as 1). At low end people who most of the people don't appreciate (1, coded as 10). ICC: 0.700	S 2013
		Life enjoyment	1−7	4 = 1, 10 = 7	Overall enjoyment of current life (in school grade points 4-10). ICC: 0.722	S 2013
		Parents willing to help if problems at school	1−5	totally agree = 1, totally disagree = 5	From I totally agree to I totally disagree. ICC: 0.661	S 2013
		Parents are willing to discuss with teachers	1−5	totally agree = 1, totally disagree = 5	From I totally agree to I totally disagree. ICC: 0.709	S 2013
		Parents encourage to success in school	1−5	totally agree = 1, totally disagree = 5	From I totally agree to I totally disagree. ICC: 0.527	S 2013
		Parents interested what happens in school	1−5	totally agree = 1, totally disagree = 5	From I totally agree to I totally disagree. ICC: 0.675	S 2013
		Parents willing to help with schoolwork	1−5	totally agree = 1, totally disagree = 5	From I totally agree to I totally disagree. ICC: 0.624	S 2013
Data from registers						
		Grade point average	5.5−9.9	4.0−10.0	The average of teacher's rated academic scores including native	S 2013

					language, foreign language, physics, chemistry, mathematics, biology, geography, religion, philosophy, history, music, art, technical or textile skills, and physical education.	
		Grade point in Physical Education	6−10	4.0−10.0	Grade point in PE. Teacher's evaluation.	S 2013

cpm, counts per minute; S 2013, spring semester 2013; F 2013, fall semester 2013; S 2015, spring semester 2015; ICC, Intraclass correlation coefficient of the variable in a test-retest analysis (n=181).

ORIGINAL PAPERS

I

OBJECTIVELY MEASURED PHYSICAL ACTIVITY, BODY COMPOSITION AND PHYSICAL FITNESS: CROSS-SECTIONAL ASSOCIATIONS IN 9- TO 15-YEAR-OLD CHILDREN

by

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Objectively measured physical activity, body composition and physical fitness: Cross-sectional associations in 9- to 15-year-old children

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Abstract
The aim of this study was to examine and quantify the cross-sectional associations of body composition (BC), physical activity (PA) and sedentary time (ST) with physical fitness (PF) in children and adolescents. A sample of 594 Finnish students (56% girls), aged 9–15 (12.4 ± 1.3 years) were selected for a study performed in 2013. The measurements of the Move! monitoring system for physical functional capacity were used to measure cardiorespiratory and musculoskeletal fitness and fundamental movement skills. Moderate-to-vigorous PA (MVPA) and ST were measured objectively with an accelerometer and BC by a bioelectrical impedance analysis. Fat mass index (FMI) and fat-free mass index (FFMI) were calculated to represent height-adjusted BC. Associations were explored with a linear regression model. In general, FMI had statistically significant negative associations, while FFMI and MVPA had positive associations with PF. No statistically significant associations were observed between ST and PF. In general, FMI had the strongest association with PF, although some variation occurred with sex and PF component. However, associations were practically relevant only in 20-m shuttle run, push-up, curl-up and 5-leaps test. For example, approximately 5 kg increase in fat mass in 155 cm tall children was estimated to correspond to 8 laps in 20-m shuttle run. Similar increase in fat-free mass corresponded to +4 and +6 laps, and 10 min increase in daily MVPA +3 and +2 laps in 20-m shuttle run, in boys and girls, respectively. Understanding these associations is necessary when interpreting children's PF and designing interventions.

Keywords: *Physical fitness, physical activity, body composition, children, adolescents*

Highlights

- This study aimed to examine and quantify the associations of body composition, physical activity and sedentary timewith different components of field-based measured PF.
- Interpretation of the results suggests that adiposity had the strongest and adverse association with PF. However, the positive associations of fat-free mass and MVPA were also considerable.
- For example, 5 kg kilograms increase in fat mass in 155 cm tall child was estimated to correspond 8 laps (one stage) weaker result in 20m shuttle run, while similar increase in fat-free mass and 10 minutes increase in daily MVPA corresponded to 2–6 laps better results.
- Understanding these associations is necessary when interpreting children's PF and designing interventions.

Introduction

Physical fitness (PF) consists of cardiorespiratory, musculoskeletal (including muscular fitness and flexibility) and neuromotor fitness (Garber et al., 2011). Childhood PF has been found to be associated with positive health outcomes during childhood (Bea, Blew, Howe, Hetherington-Rauth, & Going, 2016; Ruiz et al., 2016) and adulthood (Eisenmann, Wickel, Welk, & Blair, 2005). The evidence is especially strong for cardiorespiratory (Pate, Oria, & Pillsbury, 2012) and muscular fitness (Smith et al., 2014), while the direct health benefits of the motor

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skill domain (Lubans, Morgan, Cliff, Barnett, & Okely, 2010) and flexibility (Plowman, 2014) are less evident.

PF measurements have recently been suggested as surrogate measures of health risks in children (Bangsbo et al., 2016; Ruiz et al., 2016). Several PF testing batteries are available for this population (Ruiz et al., 2011), although not all measurements have had their validity evaluated against laboratory measurements. Recently in Finland, a novel monitoring system for physical functional capacity (Jaakkola, Sääkslahti, Liukkonen, & Iivonen, 2012) was launched under the name of Move!, where the PF of every 5th- and 8th-grade (approximately 11 and 14 years old) child is assessed in comprehensive schools and the results are discussed individually with the child and their parent during health examinations (The Finnish National Board of Education).

Previous studies have shown that body composition (BC) (Ortega, Ruiz, Castillo, & Sjöström, 2008) and physical activity (PA) (Strong et al., 2005) have considerable associations with PF in children and adolescents. Although these direct associations have previously been studied, less is known about their interrelationships and practical associations with PF. Previous studies have shown inconsistent results about the scope of PA and BC on children's PF (Dencker et al., 2007; Lintu et al., 2016; Rauner, Mess, & Woll, 2013).

As PF measures are increasingly used as a tool to identify children with possible health risks, it is important to understand the associations of major modifiable correlates of PF. Determining the associations of PA and BC help us not only to understand the PF of children and adolescents better, but also to find the central variables for interventions. Moreover, the measurements used in health screening usually have a cross-sectional design and professionals are obligated to interpret and make primary decisions of child's health and well-being based on corresponding data. Therefore, the studies with this design are justified.

It is important to note that also age is a major correlate with PF as age-related growth, maturation and development have significant associations with PF (Malina, Bouchard, & Bar-Or, 2004). Therefore, age-adjusted analyses are required to achieve general recommendations for different aged children and adolescents.

This study aimed to examine and quantify the associations of BC, PA and sedentary time (ST) with different components of field-based measured PF. To our knowledge, this is the first study examining these associations with the full range of PF using objective measures of PA, ST and BC in children and adolescents.

Methods

Study design and participants

A total of 1778 students from 9 Finnish schools from grades 4 to 7 were invited to participate in a longitudinal study (2013–2015) which was part of research related to Finnish Schools' on the Move programme (LIKES Research Centre for Physical Activity and Health). A total of 971 students participated in the study (55%) and delivered a signed written consent with their main carer. Participation was voluntary and could be discontinued at any point during the research. A cross-sectional sample of baseline measurements from spring 2013 was used in this study. After excluding students with no valid PA data ($n = 204$), missing PF measurements ($n = 76$) and possible confounding factors (reported injuries, illnesses, learning difficulties or disabilities, $n = 97$), the final study population consisted of 594 apparently healthy students (56%), aged 9–15 (12.4 ± 1.3) years old.

The study setting for the measurements was approved by the Ethics Committee of the University of Jyväskylä. All measurements were carried out in accordance with the Declaration of Helsinki.

PA and ST measures

Objective measurements of PA and ST were conducted by using an accelerometer (ActiGraph GT3X +, wGT3X+, Pensacola, Florida, USA) for seven consecutive days. Participants were advised to continue their ordinary daily routines during the measurement period and instructed to wear the accelerometer on the right side of the hip during waking hours, except for water activities (e.g. shower, swimming). Data were collected in raw 30 Hz acceleration, standardly filtered and converted into 15 s epoch counts. ST (≤100 cpm) and moderate-to-vigorous PA (MVPA, ≥2296 cpm) (Evenson, Catellier, Gill, Ondrak, & McMurray, 2008) were defined from the data. Periods longer than 30 min of consecutive zero counts were defined as non-wear time (Domazet et al., 2016). Data over 20,000 cpm were considered as spurious acceleration and excluded (Heil, Brage, & Rothney, 2012). The minimum amount of adequate data was set as 500 min day^{-1} (between 7 am and 11 pm) (Cooper et al., 2015) for at least two weekdays and one weekend day. MVPA and ST were converted into a weighted mean value of MVPA and ST per day (e.g. [(average MVPA min/day of weekdays × 5 + average MVPA min/day of weekend × 2)/7]).

PF measures

PF was measured with the measurement battery included in the novel Move! monitoring system for physical functional capacity (Jaakkola et al., 2012). For more detailed descriptions of the measurements, see Supplement Document 1.

Cardiorespiratory fitness was evaluated with 20-m shuttle run where running speed is increased in 1-min interval until maximal voluntary exhaustion. Initial speed was 8.0 km h^{-1}, following speed 9.0 km h^{-1} and following increment of 0.5 km h^{-1} per stage (Nupponen, Soini, & Telama, 1999). The result was counted as the number of laps run.

Muscular fitness measurements included push-up and curl-up. Push-up (Malmberg, 2011; Pihlainen et al., 2008) measures upper-body muscular strength. Boys performed push-ups with hands and toes and girls with hands and knees on the ground. Students completed as many push-ups as possible during 1 min. The number of correctly performed repetitions was counted. Curl-up (Jaakkola et al., 2012; Plowman & Meredith, 2013) is a modified version of FitnessGram curl-up. The number of correctly performed repetitions was counted with maximal number of repetitions limited to 75.

Flexibility (Jaakkola et al., 2012) is a composite score comprised of four different multi-joint flexibility measurements. Measurements included squat, lower back extension and left and right shoulder stretch. Each student received 1 point out of each measurement that he/she performed according to the selected criteria. The maximum score in flexibility is 4 and minimum 0.

Fundamental movement skills (FMS) were selected as the representatives of the motor skills domain. FMS were evaluated with 5-leaps test and throwing–catching combination test. In the 5-leaps test (Jaakkola, Kalaja, Arijutila, Virtanen, & Watt, 2009), students performed five consecutive leaps. The first leap was performed with both legs, followed by four following alternating single-leg leaps. Landing was performed on both legs. Each student had two attempts to jump as far as they can and the best score was recorded in meters with 0.1 m accuracy. In the throwing–catching combination test (Jaakkola et al., 2012), students threw a tennis ball from 7 to 10 m distance (distance was selected according to their age and gender) to a 1.5 m × 1.5 m sized target area situated on the wall 0.9 m above the floor. Students had 20 attempts to throw the ball behind the marked line, hit the target area and catch the ball after one bounce. The number of correctly performed repetitions were counted.

The reliability (Intraclass correlation coefficient, ICC or Correlation coefficient, *r*) of the measurements are: push-up ICC: 0.76–0.94, curl-up ICC: 0.67, squat ICC: 0.62, lower back extension ICC: 0.81, shoulder stretch ICC: 0.82–0.85, 5-leaps test *r*: 0.84 and throwing–catching combination test ICC: 0.69 (Jaakkola et al., 2012).

The measurements were conducted in school's gym halls by educated research personnel. Measurements were performed on one student group (avg. 25 persons) during a 1.5 h session. The measurement techniques were explained and rehearsed prior to the official assessment.

Anthropometric and BC measurements

Body height was measured with an accuracy of 0.1 cm (Charder HM 200P scale). BC and weight were measured in light clothing using bioelectrical impedance analysis (InBody 720, Biospace Co., Ltd) prior to participating in the PF measurements. The validity of the InBody 720 has been shown to be reasonable for measuring BC in children: the Intraclass and Pearson correlation coefficients against dual-energy X-ray absorptiometry were >0.92 (Tompuri et al., 2015).

Fat percentage, body mass index (BMI, kg m^{-2}), fat mass index (FMI, kg m^{-2}) and fat-free mass index (FFMI, kg m^{-2}) were calculated (mass in kilograms divided by height in meters squared).

Questionnaire to guardians

The main carer was asked to report any injuries, illnesses or disabilities affecting the child's physical activity, physical fitness and/or school performance.

Statistical analysis

The IBM© SPSS© Statistics was used (IBM Corp. Released 2016. IBM SPSS Statistics for Windows, Version 24.0. Armonk, NY: IBM Corp.) for the analysis. Basic analyses were performed to test and obtain normally distributed data, means, standard deviations and correlations. For PF measures where the testing procedures varied between age groups, the results were initially transformed into a standardised *z*-score. The untransformed data is shown for clarity. Characteristics were compared between sex groups using independent *t*-test for continuous variables.

A linear regression model was used to explore associations of selected variables and PF. Analyses were performed separately for boys and girls. The final multivariable model consisted of age, FMI, FFMI, MVPA and ST with PF component as the dependent factor. FMI and FFMI were chosen for indicators of BC as these measures were not too highly correlated and could be placed in the same regression model. The ST was proportioned to device-wearing time. Additionally, the variation produced by MVPA was removed from the ST variable, i.e. the shared variance between MVPA and ST, resulting into an ST residual variable that is no longer correlated with MVPA. With this procedure, the collinearity of the model can be controlled and the independent associations of the ST explored (Sequential regression, Dormann et al., 2013).

Standardised regression coefficients (Stand. β) were used to indicate the direction of the associations and their comparable strength, and coefficients of determination (R^2) to indicate the model's robustness. The unstandardised regression coefficients (Unstand. β) were used to calculate practically relevant associations between BC, PA and PF. Statistical significance level was set at $p < .05$.

Results

Participant characteristics and group differences between boys and girls are shown in Table I.

Direction, significance and comparable strength for the associations of FMI, FFMI, MVPA and ST can be seen in boys (Table II) and girls (Table III) from standardised regression coefficients (Stand. β). For boys and girls, respectively, the regression model explained (R^2) 45.5% and 34.1% of the variance in cardiorespiratory fitness, 18.0–37.4% and 13.8–30.2% of the variance in muscular fitness, 6.1% and 5.1% of the variance in flexibility and 17.6–67.8% and 11.6–47.4% of the variance in FMS. In general, FMI was negatively associated, while FFMI, MVPA and age had positive associations with PF. Sedentary time had no statistically significant association with any of the PF components (Tables II and III). Correlation coefficients for boys and girls between used variables are shown in Supplement Table I.

Measurement-specific associations

20-m shuttle run. FMI had the strongest association with 20-m shuttle run in boys and girls ($p < .001$ and $p < .001$, respectively). MVPA ($p < .001$, $p < .001$) and FFMI ($p = .003$, $p < .001$) had also significant associations in both genders (Tables II and III).

Based on unstandardised regression coefficients of the linear regression model, the estimated practical associations (Table IV) showed that approximately 5 kg increase in fat mass in 155 cm tall children was equivalent of −8 laps in the 20-m shuttle run in boys and girls. Similar increase in fat-free mass corresponded to +4 and +6 laps and 10 min increase in daily MVPA +3 and +2 laps, in boys and girls, respectively.

Push-up. FMI had the strongest association in boys and girls ($p < .001$ and $p < .001$, respectively). In addition, only FFMI ($p < .001$) was associated with push-up in boys, while in girls, FFMI ($p < .001$) and MVPA ($p = .005$) had significant associations (Tables II and III).

Approximately 5 kg increase in fat mass in 155 cm tall children was equivalent of −6 repetitions in push-up in boys and girls (Table IV). Similar increase in fat-free mass corresponded to +5 and +8 repetitions, in boys and girls, respectively. Ten minutes increase in daily MVPA was equivalent of +1 repetition in girls, while in boys the association was not statistically significant.

Curl-up. FFMI had the strongest association with curl-up in boys ($p = .001$). In girls, FMI had the strongest association ($p < .001$), although FFMI was quite equally associated ($p < .001$). No other statistically significant associations were observed in girls. In boys, in addition, FMI ($p = .003$) and MVPA ($p = .002$) were associated with curl-up (Tables II and III).

Approximately 5 kg increase in fat mass in 155 cm tall children was equivalent of −4 and −6 repetitions in curl-up in boys and girls, respectively (Table IV). Similar increase in fat-free mass corresponded to +6 and +9 repetitions, in boys and girls, respectively. Ten minutes increase in daily MVPA corresponded to +2 repetitions in boys, while in girls, the association was not statistically significant.

Flexibility. FMI was the only factor associated with flexibility both in boys and girls ($p = .001$, $p = .001$, respectively) (Tables II and III).

Practical associations of fat were minor and corresponded to less than one (< −1) score point in flexibility.

5-leaps test. FMI had the strongest association in boys and girls ($p < .001$ and $p < .001$, respectively). FFMI ($p < .001$, $p < .001$) and MVPA ($p = .005$, $p = .030$) were also associated in both genders (Tables II and III).

Approximately 5 kg increase in fat mass in 155 cm tall children was equivalent of −60 cm in 5-leaps test in boys and girls (Table IV). Similar increase in fat-free mass was equivalent of +60 cm in boys and girls. Ten minutes increase in daily MVPA corresponded to +10 cm in boys and girls.

Throwing–catching combination test. In boys, MVPA had the strongest association ($p < .001$), with FMI ($p < .001$) and FFMI ($p = .030$) also associated. In girls, only FFMI ($p < .001$) had a statistically significant association.

Table I. Participant descriptives and group differences in characteristics between sexes

Descriptives	All subjects (*n* = 971)	Apparently healthy subject group (*n* = 594) Mean (SD)	Boys (*n* = 263) Mean (SD)	Girls (*n* = 331) Mean (SD)	*p*-Value[a]
Age	12.6 (1.3)	12.4 (1.3)	12.4 (1.3)	12.4 (1.3)	.79
Physical fitness					
Cardiorespiratory fitness					
20-m shuttle run (laps)	41.6 (19.0)	42.6 (18.2)	48.3 (19.5)	38.0 (15.6)	<.001
Muscular fitness					
Push-up (repetitions)	20.1 (13.2)	21.0 (12.9)	16.8 (11.5)	24.4 (12.9)	[b]
Curl-up (repetitions)	36.8 (20.6)	37.6 (20.7)	39.8 (20.9)	35.9 (20.3)	.02
Flexibility					
Flexibility score (0–4)	3.2 (0.9)	3.3 (0.9)	3.1 (1.0)	3.5 (0.7)	<.001
Fundamental movement skills					
5-leaps test (m)	8.2 (1.2)	8.2 (1.1)	8.5 (1.2)	8.0 (0.9)	<.001
Throwing–catching combination test (repetitions)	12.0 (4.9)	12.1 (4.9)	12.7 (5.1)	11.6 (4.7)	[b]
Physical activity					
MVPA (min·day-1)	52.7 (21.7)	52.1 (21.2)	58.2 (23.3)	47.3 (18.0)	<.001
ST (min·day-1)	499.7 (70.1)	499.7 (71.4)	485.5 (74.9)	511.0 (66.6)	<.001
Prevalence of MVPA ≥ 60min·day-1 (%)	34.0	33.7	44.9	24.2	<.001
Accelerometer wear time	769.9 (55.0)	769.6 (55.9)	765.9 (57.8)	772.5 (54.2)	.16
Anthropometrics and body composition					
Height (cm)	156.1 (10.4)	155.2 (10.1)	155.2 (11.1)	155.1 (9.3)	.85
Weight (kg)	46.5 (11.6)	45.2 (11.0)	44.6 (11.9)	45.7 (10.2)	.26
BMI (kg m^{-2})	18.9 (3.2)	18.6 (3.0)	18.2 (3.1)	18.8 (3.0)	.03
FMI (kg m^{-2})	3.7 (2.4)	3.5 (2.2)	2.9 (2.2)	4.0 (2.1)	<.001
FFMI (kg m^{-2})	15.2 (1.7)	15.1 (1.5)	15.4 (1.7)	14.8 (1.4)	<.001
Fat% (%)	18.4 (8.4)	17.9 (7.9)	14.7 (7.8)	20.4 (6.9)	<.001

Notes: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); FMI, fat mass index (calculated as fat mass in kilograms divided by height in meters squared); FFMI, fat-free mass index (calculated as fat-free mass in kilograms divided by height in meters squared); MVPA, moderate-to-vigorous physical activity; SD, standard deviation.
[a]*p*-Value, statistical significance value for group difference between sexes measured with independent samples *t*-test.
[b]Measurement method differed between boys and girls.

Although these associations were statistically significant, the practical associations were minor and corresponded to 1–2 repetitions in throwing–catching combination test in boys and girls (Table IV).

Discussion

Main findings

The results of our study are consistent with previous findings showing that adiposity has a strong negative association with PF (Ortega et al., 2008), while fat-free mass (Malina, 2014) and MVPA (Strong et al., 2005) have positive associations with PF. ST was not associated with any of the PF components after adjusting for age, BC and MVPA. This result was also consistent with the previous findings (Cliff et al., 2016). Interpretation of the results suggests that adiposity has the strongest and adverse association with PF. However, the positive associations of fat-free mass and MVPA are also considerable.

Previously, the possible confounding effect of adiposity with PF has been discussed. Adjusting fitness measures for body weight and/or BC have been considered (Plowman, 2014) and favourable scaling methods were recommended (Armstrong, 2017). It has been suggested that adjusting results with body weight and especially with adiposity would give more unbiased assessment of fitness (Lloyd, Bishop, Walker, Sharp, & Richardson, 2003). On the other hand, it is unclear whether adjusted results would give an accurate picture of adolescents' daily physical functional capacity (the ability to perform tasks that require physical effort) and how adjustments may affect the health-related criteria (Plowman, 2014) that has been recently developed (Ruiz et al., 2016). However, it is important to note that adiposity is highly associated with children's PF when explored with weight-bearing measures. More research is needed to achieve feasible, valid and coherent evaluation of PF in children (Armstrong, 2017; Plowman, 2014).

There was some variation, however, in the associations depending on sex and PF component. For example, fat-free mass had the strongest association with curl-up in boys and with throwing–catching combination test in girls. MVPA had the strongest association with throwing–catching combination test in boys. These anomalies can be explained by

Table II. The unstandardised regression coefficients (Unstand. β), standardised regression coefficients (Stand. β), 95% confidence intervals (CI 95%), statistical significance level (Sig.) and the total coefficient of determination (R^2) of FMI, FFMI, MVPA and ST in relation to physical fitness with boys

Boys	Unstand. β	Stand. β	CI (95%)	Sig.
Cardiorespiratory fitness				
20-m shuttle run (laps)				
FMI (kg m^{-2})	−4.203	−0.471	−5.134 to −3.272	<.001
FFMI (kg m^{-2})	1.970	0.172	0.669 to 3.270	.003
MVPA (min day^{-1})	0.269	0.321	0.187 to 0.350	<.001
Sedentary time (residual)	0.012	0.003	−0.361 to 0.384	.951
R^2	45.5%			
Muscular fitness				
Push-up (repetitions)				
FMI (kg m^{-2})	−2.846	−0.537	−3.439 to −2.254	<.001
FFMI (kg m^{-2})	2.691	0.395	1.863 to 3.519	<.001
MVPA (min day^{-1})	0.043	0.086	−0.009 to 0.095	.106
Sedentary time (residual)	−0.069	−0.033	−0.306 to 0.169	.568
R^2	37.4%			
Curl-up (repetitions)				
FMI (kg m^{-2})	−1.889	−0.197	−3.117 to −0.662	.003
FFMI (kg m^{-2})	3.016	0.244	1.300 to 4.732	.001
MVPA (min day^{-1})	0.173	0.192	0.065 to 0.280	.002
Sedentary time (residual)	0.189	0.050	−0.302 to 0.681	.449
R^2	18.0%			
Flexibility				
Flexibility score (0–4)				
FMI (kg m^{-2})	−0.107	−0.232	−0.170 to −0.044	.001
FFMI (kg m^{-2})	−0.022	−0.037	−0.110 to 0.067	.627
MVPA (min day^{-1})	0.001	0.015	−0.005 to 0.006	.823
Sedentary time (residual)	−0.018	−0.099	−0.043 to 0.007	.160
R^2	6.1%			
Fundamental movement skills				
5-leaps test (m)				
FMI (kg m^{-2})	−0.305	−0.538	−0.351 to −0.260	<.001
FFMI (kg m^{-2})	0.305	0.417	0.241 to 0.369	<.001
MVPA (min day^{-1})	0.006	0.109	0.002 to 0.010	.005
Sedentary time (residual)	0.001	0.005	−0.017 to 0.019	.910
R^2	67.8%			
Throwing–catching combination test (repetitions)				
FMI (kg m^{-2})	−0.572	−0.244	−0.873 to −0.272	<.001
FFMI (kg m^{-2})	0.464	0.154	0.044 to 0.884	.030
MVPA (min day^{-1})	0.058	0.263	0.031 to 0.084	<.001
Sedentary time (residual)	−0.053	−0.057	−0.173 to 0.068	.390
R^2	17.6%			

Notes: All models were controlled for age. FMI, fat mass index; FFMI, fat-free mass index; MVPA, moderate-to-vigorous physical activity; ST residual, sedentary time value where variation produced by MVPA and device-wearing time is removed. Coefficient of determination (R^2) represents the proportion of the variance in the fitness variable that was able to be predicted with the model.

the differences in the type of the measurement and subject group characteristics.

The pronounced role of muscle mass to curl-up, i.e. muscular fitness is logical. However, the findings from the other muscular fitness measurement (push-up) did not support this finding (where adiposity was the strongest correlate in both sexes). This is perhaps because the curl-up is less of a weight-bearing measurement than push-up, where body weight and excessive adiposity adds loading and impairs performance.

The throwing–catching combination test showed fat-free mass to have the strongest association in girls. The observations from the PF measurements showed that girls struggled to throw the ball far enough. These findings might indicate that the separative factor in girls was actually muscle strength instead of FMS. However, in boys, the strongest correlation with this task was MVPA. As Finnish boys' leisure time PA includes ball games more frequently than girls (Aarnio, Winter, Peltonen, Kujala, & Kaprio, 2002) and most ball games are considered MVPA in children (Ridley & Olds, 2008), it is logical that a higher volume of MVPA correlated with better FMS, as measured by object control skills.

Only adiposity was associated with flexibility. Although the flexibility measure included several

Table III. The unstandardised regression coefficients (Unstand. β), standardised regression coefficients (Stand. β), 95% confidence intervals (CI 95%), statistical significance level (Sig.) and the total coefficient of determination (R^2) of FMI, FFMI, MVPA and ST in relation to physical fitness with girls

Girls	Unstand. β	Stand. β	CI (95%)	Sig.
Cardiorespiratory fitness				
20-m shuttle run (laps)				
FMI (kg m^{-2})	−3.821	−0.509	−4.599 to −3.043	<.001
FFMI (kg m^{-2})	3.193	0.278	1.980 to 4.406	<.001
MVPA (min day^{-1})	0.206	0.237	0.124 to 0.288	<.001
Sedentary time (residual)	0.075	0.026	−0.249 to 0.399	.651
R^2	34.1%			
Muscular fitness				
Push-up (repetitions)				
FMI (kg m^{-2})	−3.209	−0.517	−3.872 to −2.546	<.001
FFMI (kg m^{-2})	3.792	0.400	2.759 to 4.826	<.001
MVPA (min day^{-1})	0.100	0.138	0.030 to 0.169	.005
Sedentary time (residual)	0.010	0.004	−0.266 to 0.286	.943
R^2	30.2%			
Curl-up (repetitions)				
FMI (kg m^{-2})	−3.155	−0.324	−4.312 to −1.998	<.001
FFMI (kg m^{-2})	4.642	0.311	2.838 to 6.445	<.001
MVPA (min day^{-1})	0.102	0.090	−0.020 to 0.223	.101
Sedentary time (residual)	0.344	0.091	−0.138 to 0.825	.161
R^2	13.8%			
Flexibility				
Flexibility score (0–4)				
FMI (kg m^{-2})	−0.077	−0.216	−0.122 to −0.033	.001
FFMI (kg m^{-2})	0.018	0.033	−0.052 to 0.087	.614
MVPA (min day^{-1})	0.002	0.046	−0.003 to 0.007	.423
Sedentary time (residual)	0.002	0.011	−0.017 to 0.020	.868
R^2	5.1%			
Fundamental movement skills				
5-leaps test (m)				
FMI (kg m^{-2})	−0.273	−0.612	−0.315 to −0.232	<.001
FFMI (kg m^{-2})	0.313	0.458	0.248 to 0.377	<.001
MVPA (min day^{-1})	0.005	0.093	0.000 to 0.009	.030
Sedentary time (residual)	0.012	0.071	−0.005 to 0.029	.165
R^2	47.4%			
Throwing–catching combination test (repetitions)				
FMI (kg m^{-2})	−0.266	−0.119	−0.535 to 0.002	.052
FFMI (kg m^{-2})	0.864	0.253	0.446 to 1.282	<.001
MVPA (min day^{-1})	0.021	0.080	−0.008 to 0.049	.150
Sedentary time (residual)	−0.025	−0.029	−0.137 to 0.086	.656
R^2	11.6%			

Notes: All models were controlled for age. FMI, fat mass index; FFMI, fat-free mass index; MVPA, moderate-to-vigorous physical activity; ST residual, sedentary time value where variation produced by MVPA and device-wearing time is removed. Coefficient of determination (R^2) represents the proportion of the variance in the fitness variable that was able to be predicted with the model.

assessments and indicated overall flexibility, the selected linear regression model could detect only 5.1–6.1% of the variance in flexibility, leaving 94.9–93.9% of the variance unexplained. This largely unexplained variance indicates that flexibility has other correlates than those covered in this study. This finding supports previous knowledge that flexibility is a highly specific characteristic (Plowman, 2014).

However, although the previously mentioned associations were statistically significant, they were practically relevant only in 20-m shuttle run, push-up, curl-up and 5-leaps test. The results of the linear regression model estimated that approximately 5 kg increase in fat mass content of a 155 cm tall child was equivalent of 8 laps lower performance (approximately 1 min or one stage) in 20 m shuttle run. Similar increase in fat-free mass content and a 10 min increase in daily MVPA corresponded to approximately 2–6 laps better performance. Similar findings were found with push-up, curl-up and 5-leaps test and are presented in detail in the Results section (Table IV).

Consistency of evidence with previous studies

To our knowledge, this is the first study that examines and attempts to quantify the associations of

Table IV. Estimated practical associations of fat, fat-free mass and MVPA with PF

	Boys		Girls
Cardiorespiratory fitness			
20-m shuttle run		laps	
+5 kg Fat mass[a]	−8		−8
+5 kg Fat-free mass[a]	+4		+6
+10 min MVPA·day^{-1}	+3		+2
Muscular fitness			
Push-up		repetitions	
+5 kg Fat mass[a]	−6		−6
+5 kg Fat-free mass[a]	+5		+8
+10 min MVPA·day^{-1}	ns		+1
Curl-up		repetitions	
+5 kg Fat mass[a]	−4		−6
+5 kg Fat-free mass[a]	+6		+9
+10 min MVPA·day^{-1}	+2		ns
Flexibility		flexibility score	
+5 kg Fat mass[a]	< −1		< −1
+5 kg Fat-free mass[a]	ns		ns
+10 min MVPA·day^{-1}	ns		ns
Fundamental movement skills			
5-leaps test		cm	
+5 kg Fat mass[a]	−60		−60
+5 kg Fat-free mass[a]	+60		+60
+10 min MVPA·day^{-1}	+10		+10
Throwing–catching combination test		repetitions	
+5 kg Fat mass[a]	−1		ns
+5 kg Fat-free mass[a]	+1		+2
+10 min MVPA·day^{-1}	+1		ns

Notes: Unstandardised regression coefficients of the linear regression model were transformed to relevant measurement related values and rounded to nearest integer. <1, indicates that the association is statistically significant but corresponds less than one unit in PF. ns, association was not statistically significant.
[a]Increase by two units in fat mass index or two units in fat-free mass index were equivalent of 4.8 kg (approximately 5 kg) of fat or correspondingly fat-free mass in a 155 cm tall child.

objectively measured PA, ST and BC with cardiorespiratory and musculoskeletal fitness and FMS in children and adolescents. A few studies have explored some of these associations with resembling methods. For example, Fogelholm, Stigman, Huisman, & Metsämuuronen, 2008; Lohman et al., 2008; Dencker et al., 2007 and Lintu et al., 2016 have previously explored the associations of BC, PA and PF in children. These cross-sectional studies have shown inconsistent results on these associations and found evidence supporting either the role of PA (Fogelholm et al., 2008; Lintu et al., 2016; Lohman et al., 2008) or BC (Dencker et al., 2007) with PF. The findings our study supports the importance of BC with PF. However, it is probable that these differences depend at least partially on the differences in subject groups and used methods. A systematic review from this field is needed to further understand these associations and differences according to used methods and subject groups. Furthermore, it needs to be acknowledged that BC and PA are representatives of fairly different dimensions; they describe the status of a physical characteristic and behaviour. This is an issue which is reasonable to consider when performing direct comparisons. Our study adds to previous research by quantifying the associations of BC and PA with various components of PF. Our study also showed that some variation exists in the roles of PA and BC with PF depending on sex, PF component and the type of PF measurement.

Thus, PA and BC have both positive and negative associations with PF in children and adolescents. Furthermore, these findings suggest that it might be beneficial to balance excess adiposity, support MVPA and gain muscle mass in order to promote PF. Previous findings from intervention studies support this interpretation. Systematic reviews have shown that exercise interventions have resulted into improved fitness in children (Kriemler et al., 2011). In addition, improving the status of these variables has also resulted into decreased health risks. Ho et al. (2013) showed in their review that dietary interventions and diet-plus-exercise interventions improve metabolic profiles in children and adolescents. Notably, combining diet and exercise was found to be more efficient than exercise alone. Similarly, García-Hermoso, Ramírez-Vélez, Ramírez-Campillo, and Peterson (2016) showed in their review that combining aerobic and resistance exercise resulted in greater improvements in metabolic profiles than aerobic exercise alone.

Notably, these findings show that promoting those factors which are associated with PF might contribute not only to PF but also to reduce health risks in children and adolescents. Therefore, it is favourable to support the positively associated factors and to improve the status of adversely associated factors, with effects possibly increasing when multi-purpose procedures are performed. This is a valuable aspect to recognise while designing interventions especially for those who are obese, have a low PF level and possible health risks.

We also want to acknowledge that although this study and previous findings have not observed associations between ST and PF or health (Cliff et al., 2016) in children and adolescents, there is evidence that high ST is associated with deleterious health outcomes in adults (Biswas et al., 2015); therefore, the possible negative long-term effects of ST should not be ignored.

Strengths and limitations

The major strengths of this study are the objective assessments of PA, ST and BC with the evaluation of a full range of PF components in a large sample of children and adolescents. BMI is commonly used in studies with large participant samples as a surrogate measure of adiposity, accompanied with subjective measures of PA. Using more definitive methods provides a more objective and accurate picture of these variables.

Several limitations are noted including the cross-sectional study design that makes it impossible to explore causalities. All PF measurements were measured on school premises with field-based measurements. Although the reliability of the measures used has been shown to be reasonable (Jaakkola et al., 2012) and measurements were performed by educated personnel, more accurate assessments of the characteristics might have been obtained in a laboratory setting. The selected variables (PA, ST and BC) explained 5–68% of the variance in PF in children and adolescents, leaving an additional 32–95% of the variance unexplained. This portion of the variance might include participant motivation, amount of practice, testing conditions and equipment, tester errors, differences in running economy and heritage (Pate et al., 2012; Plowman & Meredith, 2013), which could not be addressed in this study.

Finally, although accelerometers are commonly used to detect objective intensity and duration of PA, they do not record all PA (e.g. bike riding) or the quality of the activity (cardiorespiratory, musculoskeletal or neuromotor exercise).

Conclusions

This study aimed to explore and quantify the associations of BC and PA with PF in children and adolescents. In general, adiposity had a strong negative association with PF, while fat-free mass and MVPA had positive associations with PF. No associations were observed between ST and PF. The results of this study suggest that, in general, adiposity had the strongest association with PF. The positive associations of fat-free mass and physical activity were, however, also considerable. BC and PA could explain practically relevant associations in 20-m shuttle run, push-up, curl-up and 5-leaps test. For example, 5 kg increase in fat mass in 155 cm tall child was estimated to correspond to 8 laps (one stage) weaker result in 20-m shuttle run, while similar increase in fat-free mass and a 10 min increase in daily MVPA corresponded to 2–6 laps better results.

Understanding these associations is necessary when interpreting children's PF and designing interventions. Supporting the positively associated factors (PA and gain in muscle mass) and improving the status of adversely associated factors (adiposity) may contribute advantageously not only to children's and adolescents' PF but also to health.

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II

PHYSICAL FITNESS DEVELOPMENT IN RELATION TO CHANGES IN BODY COMPOSITION AND PHYSICAL ACTIVITY IN ADOLESCENCE

by

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Title Page

Physical fitness development in relation to changes in body composition and physical activity in adolescence

Original Investigation

Running title: Fat accrual detrimental for physical fitness

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Abstract

The decline in adolescents' physical fitness (PF) in recent decades has raised concerns about current population's possible future challenges with health and physical functional capacity. This study explored the associations between body composition, physical activity, maturation, and PF development in adolescents. Furthermore, PF development of adolescents with low initial PF was assessed. A 2-year observational study was conducted between spring 2013 and 2015. Nine comprehensive schools and their 10- to 13-year-old students were invited to participate in the study (1778), and a total of 971 students (54.6%) agreed. Cardiorespiratory fitness (20-metre shuttle run), muscular fitness (push-ups), fundamental movement skills (5-leaps test), body composition (bioelectrical impedance analysis), moderate-to-vigorous physical activity (accelerometer) and pubertal status (self-assessment questionnaire) were measured at 1-year intervals. Latent growth curve modeling (LGM) was used to study PF development over time. Change in fat mass had the strongest and most coherent associations with PF development during adolescence. Fat-free mass, moderate-to-vigorous physical activity and pubertal status were associated with PF development, although not systematically. Subgroup analyses showed that PF development in the low fitness group followed a similar pattern as the whole population. However, their PF remained significantly lower throughout the 2-year period. The findings suggest that fat accumulation is an essential detrimental factor for PF development during adolescence. Actions to prevent excessive fat accumulation might help to prevent future declines in functional capacity. Indications that low fitness levels sustain during adolescence highlight the relevance of detecting these individuals and providing interventions already before adolescence.

Keywords: Children, Cardiorespiratory fitness, Muscular fitness, Fundamental movement skills, Fat mass, Fat-free mass

Introduction

Physical fitness (PF) has been found to have well-established associations with health markers during adolescence and health outcomes later in life[1]. PF can be classified into cardiorespiratory, musculoskeletal and neuromotor fitness[2]. Observational data shows that especially cardiorespiratory fitness (CRF) is positively associated with a wide range of health indicators in adolescents, including cardiometabolic, bone, and mental health[3]. Similar findings have emerged for muscular fitness (MF)[4]. In the motor fitness domain, fundamental movement skills (FMS), that is, the "building blocks of movement," are considered to be essential for children's future, and previous studies have also shown associations between FMS and some health indicators[5].

The level of PF tends to track low to moderately from adolescence into adulthood[6]. Furthermore, the epidemiological data show that PF tends to degenerate gradually after adolescence[7]. These findings emphasize the importance of detecting individuals with low PF and providing interventions already during adolescence. Major societal benefits, such as in health care costs[8], might be obtained if a sufficient amount of people could be helped to reach a sustainable level of PF at the beginning of their course of life.

Field-based measures of fitness have been widely used to assess physical fitness in European adolescents[9]. The decline in adolescents' PF performance in recent decades has raised concerns about possible challenges in future health and physical functional capacity[10,11]. Although reasons for this decline are not entirely clear, changes in physical activity and obesity levels have been proposed as explanations[11]. Increases in body mass index (BMI) have been observed simultaneously with population-level declines in PF[10].

The natural development of fitness has been previously studied in adolescents. In theory, cardiorespiratory fitness, muscular fitness, and motor skills develop with age[12]. Cardiorespiratory fitness and muscle strength typically increase alongside with growth and maturation ignited morphological and neuromuscular changes[12(chaps7, 12)]. Children typically gain fundamental gross motor skills by the age of seven and further on hone these skills[12(chap4)]. Development in strength and endurance domains also improve the performance in skill-related tasks which require maximal performance[12(chap4)]. Additionally, previous findings show that exercise can significantly improve PF[1].

However, in previous research, these associations have been assessed mainly separately, leaving a research gap for studies which analyse these associations collectively. It is notable, that the processes of biological growth and behavioural development are rather simultaneous than separate in the adolescents' lives[13]. Furthermore, the fitness development in adolescents with low fitness remains underexplored. Assessment of these factors is important while striving to understand the development of healthy and adequate fitness.

This study aimed to recognize the essential factors of natural fitness development by exploring the associations of body composition, physical activity, maturational status, and physical fitness development in adolescents based on observational data. Furthermore, the aim was to explore PF development during adolescence with a special reference to adolescents with low PF. Special interest was focused on those with low level of initial fitness due to potentially higher health risks and functional capacity deficiencies in the future. This is the first study to explore these associations in both sexes utilizing objectively measured PA and BC separated into fat and fat-free mass content.

Materials and Methods

Study design and participants

Students from nine Finnish comprehensive schools were invited to a 2-year longitudinal prospective study (1778 10- to 13-year old students). Of those invited, 971 students (54.6%; 462 boys, 507 girls, 2 with no reported gender) delivered a signed written consent form and participated in the study. This study was part of a larger research entity related to the Finnish Schools on the Move programme[14]. Baseline measurements were performed in 2013, and follow-up measurements with 1-year intervals in 2014 and 2015 (between January 14, 2013 and May 20, 2015, where measurements were conducted within the same calendar week in each school throughout the study). PF, BC, and pubertal status were measured during school-day in school's gym hall. PA measurements were informed during school-day and measured in student's habitual environments. All measurements were conducted by trained research personnel. The study setting for the measurements was approved by the Ethics Committee of the University of Jyväskylä. All measurements were carried out in accordance with the Declaration of Helsinki. The detailed procedures of the measurements (excluding assessment of maturational status) are reported by Joensuu et al.[15]

Assessments

Physical fitness

PF development was measured with a 20-metre shuttle run (measurement of CRF), push-ups, (MF), and the 5-leaps test (FMS)[15]. The 20-metre shuttle run is an incremental test that involves running until maximal voluntary exhaustion. For the push-ups, participants complete as many repetitions as possible according to selected criteria within one minute. In the 5-leaps test, participants attempt to jump as far as they can in 5 leaps.

Anthropometric and body composition measurements

Body height was measured with an accuracy of 0.1 cm (Charder HM 200P scale, Issaquah, Washington, USA). BC and weight were measured in light clothing by a bioelectrical impedance analysis device (InBody 720, Biospace Co., Ltd, Seoul, Korea). Body mass index (BMI, $kg \cdot m^{-2}$) was calculated and the prevalence of normal weight, overweight, and obesity estimated using Cole's criteria[16]. Fat mass index (FMI, $kg \cdot m^{-2}$) and fat-free mass index (FFMI, $kg \cdot m^{-2}$) were used to indicate height-adjusted BC.

Physical activity

Moderate-to-vigorous PA (MVPA) was measured objectively using a hip-worn accelerometer (ActiGraph GT3X+, wGT3X+, Pensacola, Florida, USA) during waking hours for 7 consecutive days with Evenson criteria (≥ 2296 cpm)[17]. Data were collected in raw 30 Hz acceleration using normal filter and converted into 15 s epoch counts[18]. The valid amount of data was set at ≥ 500 min/day (between 7 am and 11 pm)[19], including at least 2 weekdays and 1 weekend day.

Pubertal status

Students self-assessed their biological maturation status with a questionnaire utilizing line drawings of external primary and secondary sex characteristics categorized by the Tanner scale[20,21]. Pubertal status was defined as the mean of the two questions: (1) the developmental stage of testicles/breasts and (2) pubertal hair on a scale of 1–5.

Statistical analysis

The descriptive statistics were calculated using SPSS 20.0 for Windows (IBM Corp., Armonk, New York, USA), and all the further analyses were conducted using the Mplus statistical package (7th ed., Los Angeles, California, USA)[22].

Latent growth curve modeling (LGM) was used to study PF development over time (Spring 2013, 2014 and 2015; M1, M2, and M3, respectively) among boys and girls (please see Supporting Information 1-3 for details on the modeling procedure). In the fully adjusted model, the variation in level (initial level) and slope (rate of change over time) of PF was explained by several factors, including age, pubertal status, fat and fat-free mass, and MVPA. Both the baseline measurement M1 and the absolute change between M1 and follow-up M3 (Δ) were used. Age, pubertal status, fat mass index, fat-free mass index and MVPA explained the baseline status of PF (level) and PF development (slope). Additionally, changes in fat mass index, fat-free mass index and MVPA were used to explain PF development (slope) (Figure 1). As sensitivity analyses, fully adjusted models were rerun by replacing Δ with absolute change between M1 and follow-up M2.

Finally, the students were divided into tertiles according to their result in each of the PF measurement at baseline. The lowest tertile group was named the low fit group and their PF development pattern were compared against the whole population.

Data were clustered within classes, and therefore standard errors were calculated using the sandwich estimator to take into account nonindependence of the observations. Missing data were assumed to be missing at random (MAR). Maximum likelihood with robust standard errors was used to estimate the sample correlations and the parameters of the models. The method produces unbiased parameter estimates under MAR. The level of significance was set at P=.05 and all the tests were two-sided.

Results

Descriptive statistics

At baseline participants were 12.6 (± 1.3) and 12.5 (± 1.3) years old (boys and girls, respectively). The prevalence of overweight or obesity was 15% and 14% at baseline in boys and girls, respectively. The prevalence of participants accomplishing the physical activity guidelines for children and youth (at least 60 min of MVPA per day)[23] at baseline were 34% and 20% in boys and girls, respectively. Further descriptives are presented in Table 1.

PF development during the 2-year observational period

The mean values for PF during the observational period with 95% Confidence Intervals (95% CI) are presented in Figure 2. Performance in the fitness measures (CRF, MF and FMS) increased during the 2-year observational period in boys and girls. The trend was linear in the whole population in FMS among boys, and in CRF and MF among girls. The trend was quadratic, that is, an increment following a plateau, in CRF and MF among boys, and in FMS among girls (For model fit parameters, please see Supporting Information 1 and 2). The fitness development followed similar patterns in the low fit group (those who were in the lowest PF tertile at baseline). Furthermore, the PF of the low fit group remained significantly lower throughout the observation period. Boys and girls with low initial fitness had statistically lower PF also after 1 and 2 years compared with the whole population (in M2 and M3, respectively, and no observed overlaps in the 95% CI, Figure 2).

Factors explaining PF development

The observed associations related to PF development are presented in Table 2. For more detailed results, please see Tables in Supporting Information 4 and 5.

Cardiorespiratory fitness

Of the baseline measures (FMI, FFMI, MVPA and pubertal status) only FMI showed a statistically significant association with the CRF development in boys (standardized regression coefficient -0.17, *P*=0.007), indicating that a high initial amount of adiposity predicted a negative development in CRF in boys (Table 2). No association between baseline measures and CRF development were observed in girls.

The change in FMI had an inverse association with CRF development in both boys and girls (-0.35, *P*<0.001 and -0.34, *P*<0.001, respectively). This association was the strongest in the model, indicating that an increase in adiposity during adolescence was considerably associated with a detrimental development in CRF (Table 2). The change in FFMI was associated with CRF development only in girls (0.15, *P*=0.028), and the change in MVPA only in boys (0.25, *P*=0.015).

Muscular fitness

Baseline pubertal status and FFMI had positive associations with MF development in boys (0.23, *P*=0.025 and 0.28, *P*=0.010, Table 2), indicating that advanced pubertal status and higher amounts of fat-free mass predicted a positive development in MF. No significant associations between baseline measures and MF development were observed in girls.

The changes in BC showed significant associations with MF development. Change in FFMI showed positive associations in boys and girls (0.25, *P*=0.004 and 0.16, *P*=0.037, respectively, Table 2), indicating that increases in fat-free mass were associated with positive MF development. The change in FMI was significantly and inversely associated only in boys (-0.36, *P*=0.001). No significant associations were observed with change in MVPA (*P*=0.80 in boys and *P*=0.061 in girls).

Fundamental movement skills

Of the baseline measures, BC had significant associations with FMS development in boys (FMI -0.24, *P*=0.001 and FFMI 0.20, *P*=0.022, Table 2), indicating that high levels of initial adiposity predicted negative FMS development and high levels of initial fat-free mass the contrary. No significant associations between baseline measures and FMS development were observed in girls.

Changes in FMI had strong and negative associations with FMS development in both boys (-0.63, *P*<0.001) and girls (-0.37, *P*<0.001, Table 2). Change in FFMI showed positive associations in boys (0.28, *P*<0.001), but not in girls. No associations were observed with change in MVPA.

Sensitivity analyses

The results of the sensitivity analyses are presented in Supporting Information 6 and 7. The interpretation of the results was mainly similar to the main analyses. As an exception, change in MVPA between M1 and M2 was positively associated with CRF development (0.22, *P*=0.043) and FMS development (0.25, *P*=0.034) in girls.

Discussion

The aim of this study was to evaluate the associations between body composition, physical activity, maturation, and PF development in adolescents. The main finding was that changes in fat mass were inversely and coherently associated with PF development. This inverse association was observed in both sexes and in all explored PF characteristics, except for MF development in girls, and the association was independent of age, pubertal status, fat-free mass and MVPA. Furthermore, the aim was to evaluate the PF development of low fit adolescents. This study showed that PF in the low fitness group remained significantly lower throughout the 2-year observational period compared to the whole population. These findings emphasize that PF, measured with weight-bearing field-tests, is strongly associated with adiposity, highlighting the importance to prevent excessive fat accumulation during adolescence. These actions have potential to support normal development of PF in adolescents and decrease the incidence of potential health risks and functional capacity deficits in later life.

The detrimental associations of excessive fat accumulation with development in PF performance during adolescence are important to recognize. These findings suggest that, from a broader perspective, increments in obesity[24] might account for observed population-level declines in functional capacity[10]. Weight-bearing field-based fitness measurements are strongly associated with adiposity[15]. Adiposity is at least partially modifiable by diet and PA. Previous studies have shown an inverse dose-response association between PA and BMI in children[25]. However, indications of a bidirectional association (i.e. increased adiposity lowering PA levels) have also been shown with indications of inherent predisposition for this association[25]. These findings highlight the biological portion of these traits, and the importance of providing interventions for people with challenges in either or both these characteristics, preferably at an early age. Additionally, tackling obesity at the population level are stated to require large, societal-scale actions[26].

There were additional but not systematic associations with PF development. Baseline pubertal status and BC predicted PF development in boys but not in girls, although not systematically. Increases in fat-free mass were positively associated with development in most PF characteristics, but not all. No associations were observed between baseline MVPA and PF development. Changes in MVPA were associated with PF development only with CRF in boys.

Although the findings of our study did not indicate systematic associations between changes in MVPA and PF development, previous data from randomized controlled trials have consistently shown that different types of exercise programs, especially at a high-intensity level, improve PF[1]. It is notable that our study used data from a longitudinal observational study. A broad interpretation of these findings might indicate that during adolescence the natural changes in PA are not significant enough to produce development in PF, at least in both genders and among a variety of PF characteristics. Therefore, exercise interventions are warranted to achieve desirable changes in PF. Additionally, PA and PF are representatives of different dimensions; they describe behavior and a status of a physical characteristic. This is reasonable to consider when performing direct comparisons, especially when PA is characterized based on one-week measurement and may not exactly describe the whole year PA behavior.

Special interest was directed at those with an initially low fitness level, due to the potential for higher health and functional capacity risks in the future. PF development followed a pattern in the low fit group similar to that in the whole population. Although PF also increased in the low fit group over the 2 years of the study, it remained significantly lower throughout the observation period compared with the whole population. This phenomenon was detectable in all PF characteristics, and in both sexes. These findings imply that low PF sustain during adolescence and indicates the importance of detecting low fit individuals already prior to adolescence. Interventions during childhood might prevent possible future health and functional capacity risks in this group.

Previous longitudinal studies on examining associations between PA, BC and PF development in children or adolescents are rare[27,28]. Augste et al., utilizing LGM, had findings similar to those in our study: self-reported baseline PA affected the level but not the slope of PF in 8-year-old children[28]. In contrast to our study, Aires et al., utilizing linear regression models, found that changes in self-reported PA index were positively associated with PF development in adolescents independent of age, gender, baseline fitness level, BMI and sedentary time[27]. Our study's findings showed that changes in accelerometer-measured MVPA were associated with PF development only in CRF in boys. Further research is needed to elucidate these associations.

Augste et al. reported no association between baseline BMI and PF development, and Aires et al. found an inverse association between change in BMI and PF development. Our study supported both of these findings: more systematic associations were observed with PF development and changes in BC than with baseline BC, especially in girls. Our study adds to current knowledge by demonstrating the separate associations of fat and fat-free mass and indicating associations independent of pubertal status.

The strengths of our study include accelerometer-based assessments of PA, BC analytics which separate fat and fat-free mass and a large subject sample. Furthermore, the observational longitudinal study design and selected data analytics provide additional insights into the studied associations.

Our study did have a number of limitations worth noting. Of the 1710 students invited to the study, only 970 students (54.6%) participated. Participants were more often girls (52% vs 40%) and had higher CRF (47 vs 42 laps) compared with their non-participating peers. Accelerometer measurements suffered from drop-out: 46.5% of the participants had information from M1 and M2 measurement points, and 29.3% from M1 and M3 (see Supporting Information 1). Furthermore, more accurate data would have been obtained with 24-h registration. Although the reliability of the PF measures is reasonable[15] and measurements were performed under the supervision of educated personnel, more accurate assessments of the characteristics might have been obtained in a laboratory setting. The authors recognize that fitness measures used in this study, e.g. the 20-m shuttle run, give an estimation of the fitness and are not direct measures of fitness[29]. Accelerometers do not record all PA (e.g., bike riding) or the quality of the PA (is it CRF, MF or FMS enhancing). Although the pubertal status assessment has been shown to be valid[21], some variation might occur between self-assessment and a clinical evaluation.

One of the methodological findings of this study was that development in PF was more difficult to explain than the status of PF. The explanatory rates of the analyses were higher for the PF level than they were for slope. The final model could explain 40-48%, 40-46% and 58-71% of the variance in the level of CRF, MF and FMS (see Tables in Supporting Information 8 and 9). Similar explanation rates were 20-24%, 13-28% and 36-46% for the change in CRF, MF and FMS, respectively. Similar findings have been reported previously[28]. A few explanations for this phenomenon were considered: 1) The phenotype is reasonably stable already during adolescence and changes are more difficult to detect than status. 2) The development of PF is confounded by the initial level of PF. The model cannot be adjusted with initial PF in the LGM. However, additional sensitivity analyses showed no robust or systematic differences in the associations with fitness level (results not shown). 3) The development of PF could be confounded by the regression to the mean phenomena. 4) The development in PF during adolescence is associated with other/additional factors not covered in this study. PF development could be influenced by, for example, societal, social, psychological and other physical factors such as heritage, which were not investigated in this study. Further research is needed to identify the most relevant factors associated with adolescent PF development.

Perspective

PF is associated with several favourable outcomes in adolescents. However, current adolescents' PF performance is notably lower than their parents'[10,11]. In the future, actions are recommended to prevent potential adverse outcomes related with declined population levels of field-based measured PF.

This study adds to previous knowledge by showing that the PF development in the low fit subgroup of adolescents followed a similar pattern to what was observed in the whole population. However, the low fit group remained to have a significantly lower PF in all characteristics throughout the observation period. Furthermore, this study demonstrated that especially fat mass accrual was considerably associated with detrimental development in PF performance. Other explored variables also had associations with PF development, but these were not systematic.

These findings emphasize the importance for actions to prevent excessive fat accumulation during adolescence. These actions might support optimal development of PF performance and decrease the incidence of potential health risks and functional capacity deficits in later life. Findings that low fitness levels sustain during adolescence indicate the importance of detecting these individuals and providing interventions already prior to adolescence.

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Conflict of Interest

The authors declare no conflict of interest.

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Figure legends

Figure 1. The basic structure of the latent growth curve analysis with the final multivariable model.

Footnotes: PF, physical fitness; Pube, Pubertal status at baseline, FMI, fat mass index at baseline; FFMI, fat-free mass index at baseline; MVPA, Moderate-to-vigorous physical activity at baseline; Δ, difference score between measurements in Spring 2013 and Spring 2015; M1 measurements in Spring 2013; M2, measurements in Spring 2014; M3, measurements in Spring 2015; 1 and 2, The fixed values of the factor loadings; LEVEL, latent variable of the initial level of PF; SLOPE, latent variable of the rate of change over time.

Figure 2. The 2-year physical fitness development patterns for boys and girls with 95% Confidence Intervals

Footnotes: Solid line, the average physical fitness (PF) development in the whole population; Dashed line, the average PF development in the low fit group; Dotted lines, 95% Confidence intervals; CRF, Cardiorespiratory fitness (20-m shuttle run, laps); MF, Muscular fitness (Push-up, repetitions, measurement technique differed between boys and girls); FMS, Fundamental movement skills (5-leaps test, meters). M1, measurements in Spring 2013; M2, measurements in Spring 2014; M3, measurements in Spring 2015;

Supporting Information 1. Text. Latent growth curve modeling (LGM)
Supporting Information 2. Table. Model-fit indices of the unconditional models for physical fitness.
Supporting Information 3. Table. The estimation results of unconditional latent growth models for physical fitness among boys and girls: the means and the variances of growth factors.
Supporting Information 4. Table. The results of latent growth curve modeling among boys: the associations related to physical fitness development (slope).
Supporting Information 5. Table. The results of latent growth curve modeling among girls: associations related to physical fitness development (slope).

Supporting Information 6. Table. The results of the sensitivity analyses among boys: associations related to physical fitness development (slope).

Supporting Information 7. Table. The results of the sensitivity analyses among girls: associations related to physical fitness development (slope).

Supporting Information 8. Table. The results of latent growth curve modeling among boys: associations related to physical fitness level.

Supporting Information 9. Table. The results of latent growth curve modeling among girls: associations related to physical fitness level.

Table 1. Descriptive statistics of the study sample at baseline

	Boys (n=462)	Girls (n=508)
Age (years)	12.6 ± 1.3	12.5 ± 1.3
Physical fitness		
CRF (20-m shuttle run, laps)	47.5 ± 20.3	37.0 ± 15.9
MF (Push-up, repetitions)[a]	16.7 ± 11.7	23.9 ± 13.2
FMS (5-leaps test, m)	8.5 ± 1.2	8.0 ± 1.0
Physical activity		
MVPA (min·day-1)	59.2 ± 23.7	47.5 ± 18.4
Prevalence of MVPA ≥ 60min·day^{-1} (No., %)	159 (34.4%)	101 (19.9%)
Accelerometer wear time	765.3 ± 56.1	773.6 ± 53.9
Anthropometrics, body composition and maturation		
Height (cm)	156.7 ± 11.3	155.5 ± 9.5
Weight (kg)	46.5 ± 12.7	46.5 ± 10.6
BMI (kg·m^{-2})	18.6 ± 3.3	19.1 ± 3.2
Prevalence of overweight and obesity[b] (No., %)	62 (15%)	69 (14%)
FMI (kg·m^{-2})	3.1 ± 2.3	4.2 ± 2.3
FFMI (kg·m^{-2})	15.6 ± 1.8	14.8 ± 1.4
Fat% (%)	15.3 ± 8.2	21.2 ± 7.5

Pubertal status[c]	2.7 ± 1.0	2.6 ± 0.9

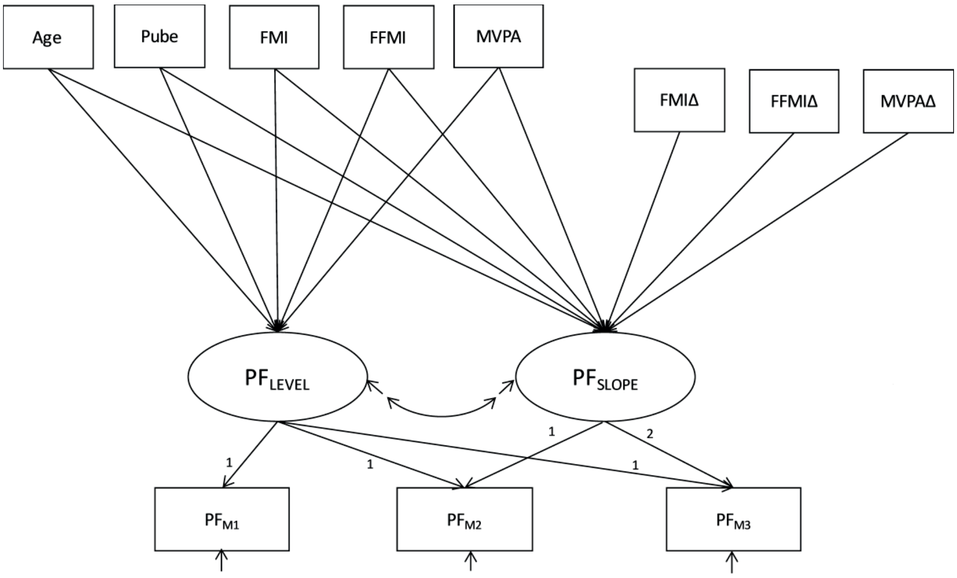
Footnotes: Units are means and standard deviations unless other mentioned; CRF, Cardiorespiratory fitness; MF, Muscular fitness; FMS, Fundamental movement skills; MVPA, Moderate-to-vigorous physical activity; BMI, Body mass index; FMI, Fat mass index; FFMI, Fat-free mass index; a, The measurement technique differed between boys and girls; b, Classification is based on Cole's thresholds; c, Classification is based on self-assessment questionnaire and Tanner's scale.

Table 2. The associations of explored variables with physical fitness development (slope) in boys and girls.

	Boys		**Girls**	
CRF slope	B (SE)	P value	B (SE)	P value
Pube	0.12 (0.09)	0.19	-0.04 (0.10)	0.72
FMI	-0.17 (0.06)	0.007	-0.07 (0.08)	0.39
ΔFMI	-0.35 (0.07)	<0.001	-0.34 (0.10)	<0.001
FFMI	0.08 (0.10)	0.42	0.08 (0.08)	0.30
ΔFFMI	0.11 (0.07)	0.12	0.15 (0.07)	0.028
MVPA	0.09 (0.09)	0.28	0.14 (0.11)	0.18
ΔMVPA	0.25 (0.10)	0.015	0.17 (0.12)	0.18
R^2	0.20		0.24	
MF slope	B (SE)	P value	B (SE)	P value
Pube	0.23 (0.10)	0.025	0.09 (0.11)	0.40
FMI	-0.17 (0.09)	0.074	0.06 (0.07)	0.38
ΔFMI	-0.36 (0.11)	0.001	-0.12 (0.08)	0.13
FFMI	0.28 (0.11)	0.010	-0.10 (0.09)	0.26
ΔFFMI	0.25 (0.09)	0.004	0.16 (0.07)	0.037
MVPA	0.07 (0.15)	0.63	0.11 (0.09)	0.20
ΔMVPA	0.05 (0.20)	0.80	0.24 (0.13)	0.061
R^2	0.28		0.13	

FMS slope	B (SE)	P value	B (SE)	P value
Pube	0.12 (0.11)	0.25	-0.18 (0.10)	0.057
FMI	-0.24 (0.07)	0.001	-0.10 (0.08)	0.19
ΔFMI	-0.63 (0.11)	<0.001	-0.37 (0.10)	<0.001
FFMI	0.20 (0.09)	0.022	0.12 (0.10)	0.20
ΔFFMI	0.28 (0.07)	<0.001	0.16 (0.10)	0.096
MVPA	-0.05 (0.12)	0.68	0.04 (0.11)	0.70
ΔMVPA	-0.13 (0.19)	0.49	0.00 (0.13)	0.99
R^2	0.46		0.36	

Footnotes: All models were adjusted for age; CRF, Cardiorespiratory fitness; MF, Muscular fitness; FMS, Fundamental movement skills; Slope, Latent variable of the rate of change over time; Pube, Pubertal status; FMI, Fat mass index; FFMI, Fat-free mass index; MVPA, Moderate-to-vigorous physical activity; Δ, difference score between measurements in Spring 2013 and Spring 2015; B, Standardized regression coefficient; SE, Standard error; R^2, Coefficient of determination



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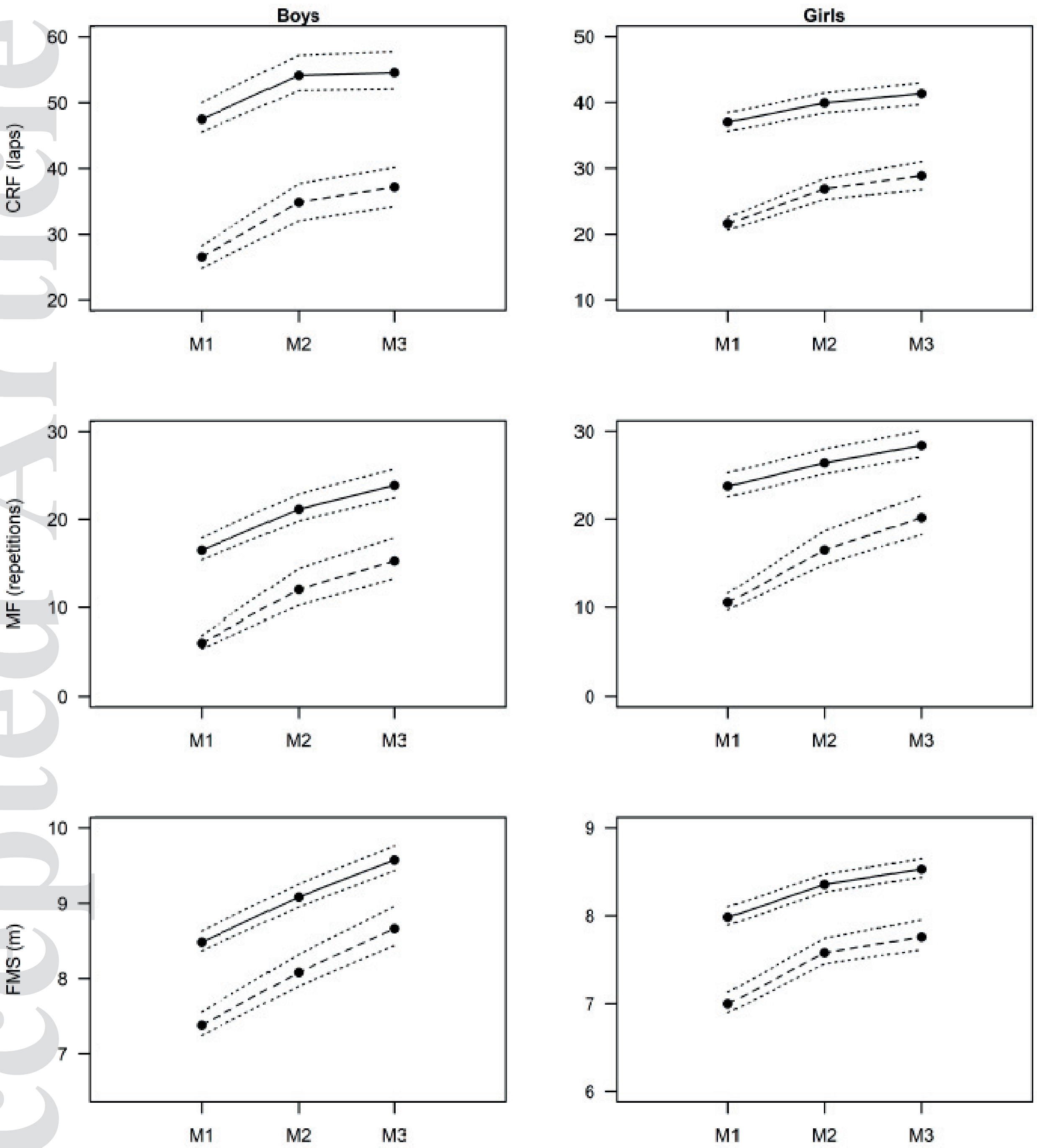

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III

PRECISION EXERCISE MEDICINE: PREDICTING UNFAVOURABLE STATUS AND DEVELOPMENT IN THE 20-M SHUTTLE RUN TEST PERFORMANCE IN ADOLESCENCE WITH MACHINE LEARNING

by

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Precision exercise medicine: predicting unfavourable status and development in the 20-m shuttle run test performance in adolescence with machine learning

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ABSTRACT

Objectives To assess the ability to predict individual unfavourable future status and development in the 20m shuttle run test (20MSRT) during adolescence with machine learning (random forest (RF) classifier).

Methods Data from a 2-year observational study (2013–2015, 12.4±1.3 years, n=633, 50% girls), with 48 baseline characteristics (questionnaires (demographics, physical, psychological, social and lifestyle factors), objective measurements (anthropometrics, fitness characteristics, physical activity, body composition and academic scores)) were used to predict: (Task 1) unfavourable future 20MSRT status (identification of individuals in the lowest 20MSRT tertile after 2 years), and (Task 2) unfavourable 20MSRT development (identification of individuals with 20MSRT development in the lowest tertile among adolescents with baseline 20MSRT below median level).

Results Prediction performance for future 20MSRT status (Task 1) was (area under the receiver operating characteristic curve, AUC) 83% and 76%, sensitivity 80% and 60%, and specificity 78% and 79% in girls and boys, respectively. Twenty variables showed predictive power in boys, 14 in girls, including fitness characteristics, physical activity, academic scores, adiposity, life enjoyment, parental support, social status in school and perceived fitness.

Prediction performance for future development (Task 2) was lower and differed statistically from random level only in girls (AUC 68% and 40% in girls and boys).

Conclusion RF classifier predicted future unfavourable status in 20MSRT and identified potential individuals for interventions based on a holistic profile (14–20 baseline characteristics). The MATLAB script and functions employing the RF classifier of this study are available for future precision exercise medicine research.

Key messages

What is already known

- The 20-m shuttle run test is commonly used in adolescents to estimate unfavourable cardiorespiratory fitness
- Currently used methods for assigning interventions based on the 20-m shuttle run test have limitations in individual level accuracy

What are the new findings

- Machine learning algorithm was able to identify adolescents with unfavourable future 20 m shuttle run test (20MSRT) status based on 14 baseline characteristics in girls, and 20 in boys.
- This study provides an example with attached MATLAB script and functions how to use machine learning in precision exercise medicine.
- Adolescents' overall physical, psychological and social status are recommended to be assessed before deciding on interventions based on the 20MSRT score.

INTRODUCTION

Precision medicine is prevention and treatment strategies of diseases taking the individual variability into account.[1] Recently, a similar concept called precision exercise medicine was brought forward where the role of physical activity (PA) and cardiorespiratory fitness (CRF) in health enhancement was acknowledged.[2] However, currently, the focus in precision exercise medicine is mainly on exploring treatment procedures and exercise response variability in adults.[2 3] Nevertheless, many chronic diseases have origins already in early childhood.[4] Prevention strategies warrant more focus on children and adolescents, especially as health risks have associations with CRF[5] and reversibility with exercise interventions in this age group.[6]

The 20-m shuttle run test (20MSRT) is the most commonly used field test to estimate CRF.[7] Low 20MSRT score has adverse associations with many aspects of children's and adolescents' daily lives. Previous studies have reported 20MSRT associated with lower overall physical performance,[8] poorer tissue health (including adiposity,[8] brain[9] and bone tissue[10]), lower cardiometabolic and psychosocial health, and cognitive performance.[8]

However, currently used methods to assign interventions based on the 20MSRT have limitations by their individual level accuracy.[7 11] The ability to predict 20MSRT prospects during adolescence would enhance the identification of potential individuals for lifestyle interventions.

Machine learning (ML)-based pattern recognition approaches have emerged as promising alternatives to traditional statistical methods in precision exercise medicine.[3] Random forest (RF) is a commonly used ML algorithm. Contrary to other high learning capacity methods, such as neural networks and support vector machines, major advantages of RF include that the extensive tuning of hyperparameters is not required and overfitting the model is usually of lesser concern. An additional benefit especially suited for our research goals is extracting the estimates of importance for each variable in the data.[12 13] The main aim of this study was to evaluate the performance of RF on predicting future individual unfavourable 20MSRT status and development during adolescence based on 48 baseline variables, including physical, psychological and social indicators. Two prediction tasks were implemented: (Task 1) prediction of unfavourable future 20MSRT status (identification of individuals in the lowest 20MSRT tertile after 2 years), and (Task 2) prediction of unfavourable 20MSRT development in adolescents with limitations in their 20MSRT performance (identification of individuals with 20MSRT development in the lowest tertile among adolescents with baseline 20MSRT below median level). Task 1 focuses on the normal population, while Task 2 focuses specifically on children and adolescents who are more likely to experience the adverse outcomes related to lower 20MSRT performance.

We hypothesised that the baseline data contain variables that can predict future 20MSRT status and development. A secondary aim was to evaluate with a data-driven approach the best predictors of unfavourable 20MSRT prospects out of a wide range of baseline characteristics. We furthermore provide the predictive modelling algorithms used in this study for future research.

METHODS

Study design and participants

Secondary data analyses were performed for data collected in a 2-year longitudinal observational study (2013–2015) related to the Finnish Schools on the Move programme.[14] Data contained information from 971 students (mean 12.5±1.3 years, min 9.2 years, max 15.3 years, 52% girls). The sample of this study was further reduced to 633 (50% girls) (Task 1) and 300 subjects (50% girls) (Task 2), described in more detail in the Predictive modelling section. The data were collected at baseline during Spring and Fall semesters (1 May 2013 and 8 November 2013) and at follow-up during the Spring semester (1 May 2015) in nine Finnish public schools. The baseline and follow-up measurements during the Spring semester were performed within the same calendar week in each school.

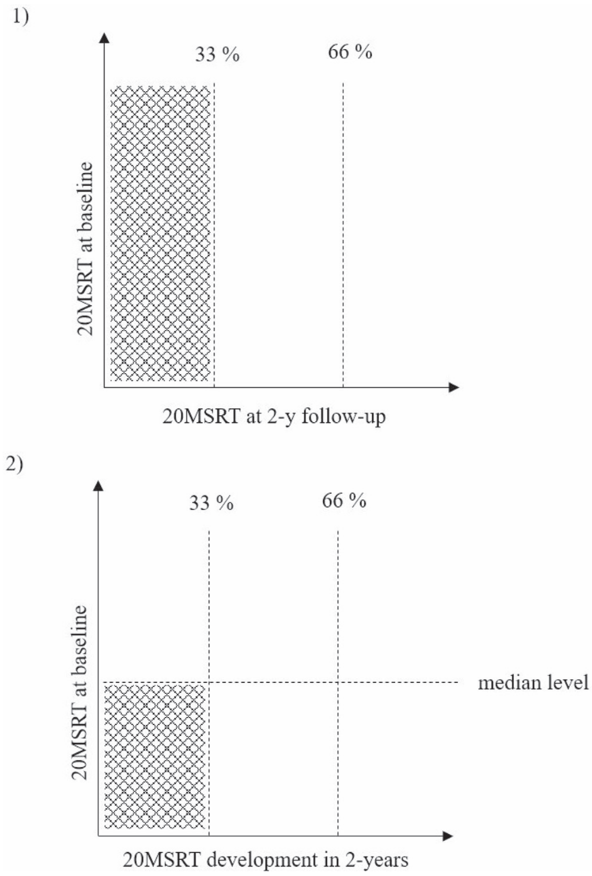

Figure 1 Prediction tasks were (A) unfavourable future 20MSRT status (identification of individuals in the lowest 20MSRT tertile after 2 years), and (B) unfavourable 20MSRT development in adolescents with limitations in their 20MSRT performance (identification of individuals with 20MSRT development in the lowest tertile among adolescents with baseline 20MSRT below median level). Both of these target tertile groups are highlighted in grey. The exact outcome variables to be predicted were (A) status of 20MSRT at follow-up (laps) and (B) absolute change between baseline and follow-up (in laps). The median level refers to the 50% performance level that was determined for each age cohort and both sexes separately to select the study sample in Task 2. The 33%, 66% cut-offs represent the tertiles used in Tasks 1 and 2. In both tasks, the outcome tertiles were determined for each age cohort and both sexes separately. 20MSRT, 20-m shuttle run test.

Forty-eight baseline variables (see the full list in online supplemental information document 1) were used in the prediction tasks (figure 1). Information regarding participants' demographics, physical, psychological and social factors was obtained from self-assessment questionnaires and non-invasive objective measurements.

Self-assessment questionnaires

Participants completed two web-based questionnaires at baseline. Due to the extensiveness of the questionnaires, the data were collected in two parts: a first round during the Spring 2013 and a second during the Fall 2013 semester (see division in online supplemental information document 1). In addition to basic demographic information (age and sex), the questionnaires assessed student's perceptions of their physical, psychological, and social status and health-related behaviour, for example, subjective evaluation of PA,[15] pubertal status on Tanner scale,[16] societal status of the family,[17] perceived health,[18] and cigarette, alcohol, and unhealthy food consumption.

Objective measurements

All objective measurements were performed during the Spring semester of 2013. Body height was measured with an accuracy of 0.1 cm (Charder HM 200P scale). Body composition and mass were measured in light clothing using a bioelectrical impedance analysis device (InBody 720, Biospace Co.). Waist circumference was measured according to WHO guidelines.[19]

Physical fitness measurements were conducted in schools during the school day, with measurements included in the Finnish national Move!—monitoring system for physical functional capacity[20]: 20MSRT, push-up, curl-up, 5-leaps test, throwing–catching combination test and flexibility. Procedures for fitness measurements are described in detail in our previous baseline article.[21] The 20MSRT followed the Eurofit protocol and was recorded as laps run until voluntary exhaustion.

Device-based PA was evaluated using a hip-worn accelerometer (ActiGraph GT3X+, wGT3X+, Pensacola, Florida, USA) during a 7-day measurement period with raw 30 Hz acceleration, standard filtering and 15 s epoch conversion. Evenson criteria were used to define sedentary (<100 counts/min (cpm)), light (101–2295 cpm), moderate-to-vigorous (2296–20 000 cpm) physical activity (MVPA).[22] The valid amount of data was set for at least 500 min/day (between 07:00 and 23:00),[23] including at least 2 weekdays and 1 weekend day. Activity intensities were converted into weighted mean values per day (eg, MVPA=((average MVPA min/day of weekdays×5+average MVPA min/day of weekend days× 2)/7)).

Academic scores (teacher-rated grade points) included grade point average (GPA) and grade point in physical education. Regional education services provided the data.

Predictive modelling

The predictive modelling algorithms are provided in a data file (online supplemental information document 2) and available for future studies. All analyses were performed using MATLAB R2018a with the Statistics and Machine Learning Toolbox and conducted separately for both sexes.

The flow chart of predictive modelling is presented in figure 2. Please see the full details of the analyses in the online supplemental information document 3.

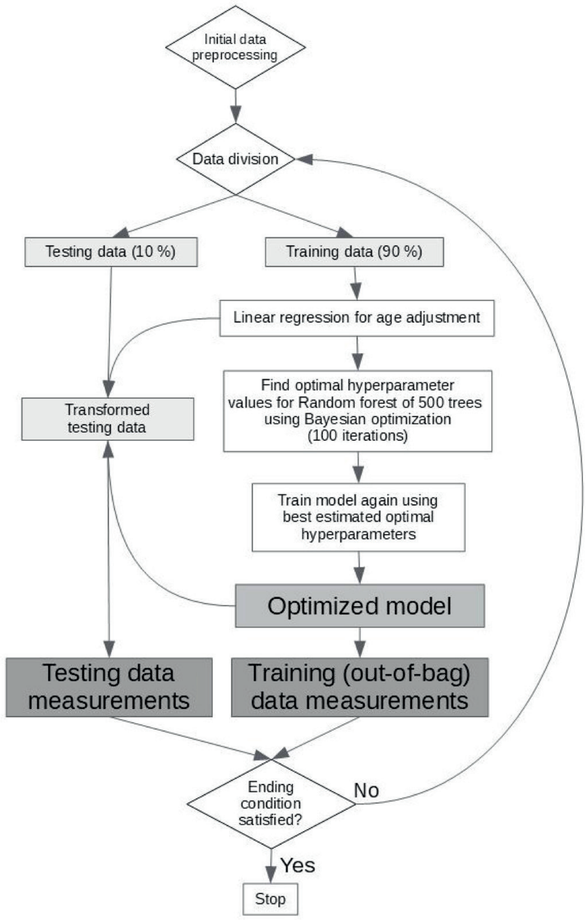

Figure 2 The flow chart of predictive modelling.

Initial data preprocessing

Target variable formatting

The target variables to be predicted were (1) status of 20MSRT at follow-up and (2) absolute change in 20MSRT test result (laps) between the baseline and the follow-up (figure 1). The tertile groups were determined for both sexes and each age cohort separately. From a total of 971 observations, the 20MSRT baseline level could be determined for 871 students. A total of 633 participants were included in the Task 1 analysis. Exclusion criteria included participants with no result from the 20MSRT follow-up test. Here the missing mechanism was assumed to be missing completely at random. Altogether 300 adolescents were included in the Task 2 analyses. These participants had a recorded result for both 20MSRT tests, and their baseline 20MSRT result was below the age-specific and sex-specific median level. Here participants with no results from either of the two 20MSRT tests were excluded from the analysis.

Variables heavily dependent on age (see online supplemental information document 3 for a list) were age-adjusted using linear regression. The age-adjustment was first performed for the training data, and the residual information was thereafter used to age adjust the corresponding variables in the testing data.

Data division

The 10-fold cross-validation (CV) was used for model assessment where the data set (eg, in Task 2: n=150 boys, n=150 girls) was divided into 10 subsamples (n=15 participants per subsample) called folds. Nine folds were then used as the training data (90% of the whole data set, to fit the tree model and estimate the variable importance values) and one fold as the testing data (10% of the whole data set, to evaluate the prediction accuracy on an independent sample). The procedures of training and prediction were then performed for these folds in a rotating manner, where eventually, all the folds had been used for training and testing. These procedures provided in total a set of 10 data-driven prediction models. The average performance of these 10 prediction models is shown in the Results section.

Training and prediction

RF is an ML method that grows a forest of multiple de-correlated decision trees.[13] This forest of trees is thereafter employed as a voting ensemble, where each tree votes for the group of a single student (ie, does the individual belong to the lowest, middle or highest tertile group). The final predicted group for the student has the most votes in the whole forest.[12 13] For each of the 10 folds, the trained model was employed to predict the testing portion of data. The area under the receiver operating characteristic curve (AUC), sensitivity and specificity metrics were recorded. A t-test in MATLAB was performed for AUC results to determine if the mean was significantly ($p<0.05$) above the random level of 0.5.

The prediction strength of each feature is estimated using the out-of-bag (OOB) samples of each tree, that is, training data samples that have not been used when forming the tree. The OOB samples are shown to the tree, and the F1-score measure (online supplemental information document 3) of the predictions are recorded. Then the values of each feature are permuted one-by-one randomly, and after each permutation, the classification error is calculated again. This procedure is applied to all the trees in the forest. The final estimate of individual feature importance is the difference between the original classification error and the randomly permuted feature classification error, averaged for all the trees.[12] The final list of statistically significant ($p<0.05$) predictors (online supplemental information document 5) was then formed, using MATLAB's t-test function. T-test was again performed for each predictor to determine which feature importance estimates were significantly above the mean of zero, indicating that they had predictive power.

The direction of the associations

The directions for the significant variables (significance set at $p<0.05$, presented in figures 3 and 4) were estimated using a separate receiver operating characteristic (ROC) analysis.[24] The analysis was performed for the two prediction tasks, separately for girls and boys. Here, the whole data were employed without separation to training and testing data sets. Each variable in the data was then used one by one. The idea was to see how well a single variable can separate the data into two groups: the first group contained the lowest tertile and the second group contained the two upper tertiles. The separation threshold in the analysis is then changed step-by-step. At each step, two metrics needed for the ROC curve, sensitivity and specificity, are recorded. For each variable, we recorded the AUC value. The AUC value was then compared with

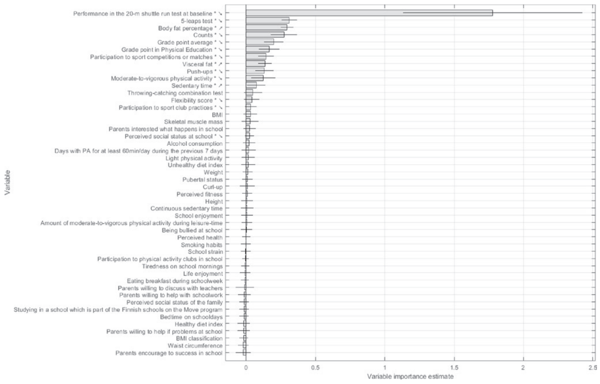

Figure 3 Best predictors for Task 1 in girls (20MSRT performance in the lowest tertile at 2-year follow-up). Statistically significant predictors are marked with * ($p<0.05$). Descending arrow (↘): low values are associated with 20MSRT in the lowest tertile. Ascending arrow (↗): high values are associated with 20MSRT in the lowest tertile. The solid line represents the 95% CI. Variable importance estimate indicates the significance of the predictor. 20MSRT, 20-m shuttle run test.

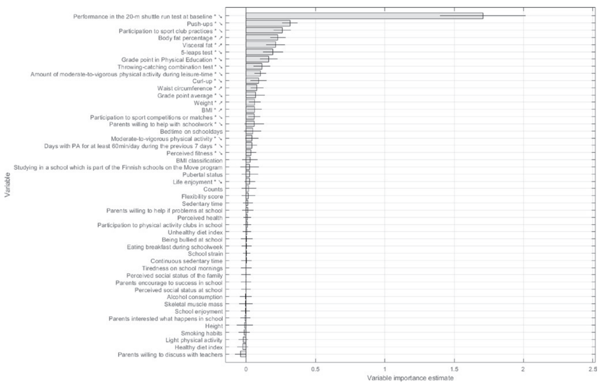

Figure 4 Best predictors for Task 1 in boys (20MSRT performance in the lowest tertile at 2-year follow-up). Statistically significant predictors are marked with * ($p<0.05$). Descending arrow (↘): low values are associated with 20MSRT in the lowest tertile. Ascending arrow (↗): high values are associated with 20MSRT in the lowest tertile. The solid line represents the 95% CI. Variable importance estimate indicates the significance of the predictor. 20MSRT, 20-m shuttle run test.

Table 1 Descriptives of the study sample at baseline

	Boys (n=319)	Girls (n=314)
Age (years)	12.5±1.3	12.3±1.3
Height (cm)	156.1±11.7	154.1±9.6
Weight (kg)	46.1±12.9	44.8±10.5
BMI (kg/m^2)	18.6±3.3	18.7±3.1
20MSRT (laps)	45.3±19.0	36.4±15.2
20MSRT centile*	60th	70th
MVPA (min/day)	58.0±22.4	48.3±17.9
Pubertal status†	2.6±1.0	2.5±0.9

Units are means and SD unless other mentioned.
*International normative values by Tomkinson *et al*, 2016.
†Classification is based on self-assessment questionnaire and Tanner's scale.
BMI, body mass index; 20MSRT, 20-m shuttle run test; MVPA, accelerometry-based moderate-to-vigorous physical activity.

the random level (0.5). If the value was higher than the random level, we assumed that the variable information is applied correctly. The associated direction was that the higher the variable value, the higher the probability of the student belonging to the lowest tertile. Additionally, if the AUC value was lower than 0.5, a simple transformation of multiplying all the variable values with the number −1 was made, and the AUC was then calculated again. In this case, the associated direction was inverted: the lower the variable value, the higher the probability of belonging to the lowest tertile. The results of the ROC analysis are presented in online supplemental information document 4.

Patient and public involvement

Patients or the public were not involved in designing, analysing or interpreting this study.

RESULTS

The characteristics of the study sample are described in table 1. Participants' average performance in the 20MSRT was 45.3 and 36.4 laps at baseline in boys and girls, representing the 60th and 70th centile in the international normative values for 20MSRT.

Prediction performance

The ability of the RF method to predict unfavourable future 20MSRT status (Task 1) is presented in table 2. The AUC values were higher in girls (0.83) than in boys (0.76), both statistically higher than the random level of 0.5 (p<0.001). Sensitivity (individuals correctly predicted to belong to the lowest performance tertile) was higher in girls (0.80) than in boys (0.60). Specificity (individuals correctly predicted not to belong to the lowest performance tertile) was 0.78 in girls and 0.79 in boys.

The ability of the RF method to predict unfavourable 20MSRT development in a group of adolescents with baseline 20MSRT below the median level (Task 2) is presented in table 2. The prediction performance of ML was lower in these analyses. The AUC values were higher in girls (0.68) than boys (0.40), but only girls' predictions statistically differed from the random level (p=0.001). Sensitivity (individuals correctly predicted to belong to the lowest development group) was higher in girls (0.59) than in boys (0.13). Specificity (individuals correctly predicted not to belong to the lowest development group) was 0.70 in girls and 0.79 in boys.

Best predictors of 20MSRT prospects

The statistically significant predictors for Tasks 1 and 2 are represented in figures 3 and 4. The x-axis in the figures gives the estimate for variable importance, calculated using the increase or decrease in classification error when the predictor values are randomly permuted separately for each predictor. The higher the estimate, the higher is the significance of the predictor. Please see detailed information related to the direction and statistical significance of the variables in online supplemental information document 4. The top predictor for Task 1 was 20MSRT performance at baseline, both in boys and girls (p<0.001, figures 3 and 4), indicating that low initial 20MSRT performance predicts low performance also after 2 years.

Girls had 13 additional predictors (figure 3): low performance in other physical fitness tests (5-leaps test (p<0.001), push-ups (p<0.001) and flexibility score (p=0.049)), high markers of adiposity (body fat percentage (p<0.001) and visceral fat (p<0.001)), low

Table 2 The overall prediction performance of the unfavourable future 20MSRT status and development

	AUC	95% CI	P value	Sensitivity	95% CI	Specificity	95% CI
Task 1	Unfavourable future 20MSRT status (identification of individuals in the lowest 20MSRT tertile after 2 years)						
Girls	0.83	0.76 to 0.90	<0.001	0.80	0.69 to 0.91	0.78	0.74 to 0.82
Boys	0.76	0.71 to 0.81	<0.001	0.60	0.52 to 0.68	0.79	0.74 to 0.84
Task 2	Unfavourable 20MSRT development (identification of individuals with 20MSRT development in the lowest tertile among adolescents with baseline 20MSRT below median level)						
Girls	0.68	0.60 to 0.76	0.001	0.59	0.50 to 0.68	0.70	0.59 to 0.81
Boys	0.40	0.29 to 0.51	0.108	0.13	0.04 to 0.22	0.79	0.70 to 0.88

P value: statistical difference of the AUC value from the random level of 0.5; Sensitivity: individuals correctly predicted to belong to the explored group; Specificity: individuals correctly predicted not to belong to the explored group.
AUC, area under the receiver operating characteristic curve; ;20MSRT, 20-m shuttle run test.

markers of PA (accelerometry-based counts (p<0.001), MVPA (p=0.003), participation to sport club practices (p=0.025) or competitions (p<0.001) and high percentage of accelerometry-based sedentary time (p=0.009)), low academic scores (GPA and grade point in physical education (both p<0.001)) and low perceived social status in school (p=0.015), all predicting placement in the lowest 20MSRT tertile after 2 years.

In addition to the baseline 20MSRT performance, boys had 19 additional predictors (figure 4): low performance in other physical fitness tests (push-ups (p<0.001), 5-leaps test (p<0.001), throwing–catching combination test (p<0.001) and curl-up (p=0.001)), high markers of adiposity (body fat percentage (p<0.001), visceral fat (p<0.001), waist circumference (p<0.001), weight (p<0.001) and BMI (p=0.005)), low academic scores (grade point in physical education (p<0.001), and GPA (p=0.015)), low markers of PA (participation to sport club practices (p<0.001) or competitions (p=0.001), self-reported PA status (two questions: p<0.001 and p=0.006) and accelerometry-based MVPA (p=0.020)), low parents' willingness to help with schoolwork (p=0.045), low perceived fitness (p=0.007) and low life enjoyment (p=0.042), all predicting future placement in the lowest 20MSRT performance tertile after 2 years.

As prediction performance for 20MSRT development was below 0.7 for both sexes, the best predictors are recommended to be interpreted with caution. These results are described in online supplemental information document 5.

DISCUSSION

Main findings

ML approach was able to predict, based on baseline characteristics, unfavourable future 20MSRT status with 0.76–0.83 (AUC) accuracy. Prediction performance was better in girls than in boys (eg, sensitivity values 0.80 in girls and 0.60 in boys). The prediction performance declined when predicting unfavourable 20MSRT development in a group of adolescents with an initial 20MSRT below the median level. These findings indicate that ML was able to identify potential individuals for interventions. Additionally, future fitness status might be easier to predict than development, at least in a group of adolescents with more homogeneous 20MSRT performance capacity.

Best predictors of individual fitness development

Our findings showed that baseline 20MSRT performance was the best predictor of future performance in a large group of adolescents. However, this study highlighted 13–19 variables (out of 48 variables) with predictive power. These variables included a low performance in other field-based physical fitness tests, low perceived fitness, high markers of adiposity, low markers of PA, low academic achievement in school, low grade in physical education, low life enjoyment, low parental support and low perceived social status at school. These findings indicate that multiple factors, that is, adolescents' overall physical, psychological and social well-being, contribute to the trajectory of the 20MSRT during adolescence. This information adds to the previous body of research where performance development is typically examined through growth and maturation ignited morphological changes.[25]

Precision exercise medicine prospects

These promising findings also provide new prospects for precision exercise medicine in adolescents. Findings suggest that preventive measures linked to the 20MSRT score benefit from the ML-enabled holistic approach. In ML, patterns are explored from the data. This has benefits as data-driven characteristic profiles can be recognised if such exist in the data. Furthermore, the CV technique helps overcome a phenomenon where models or thresholds created with traditional statistics tend to fit poorly with other data sets or future individual observations.[26] An ML approach is recommended to be considered in future precision exercise medicine studies aiming to identify potential individuals for interventions.

Our findings indicated that information from adolescents' overall physical, psychological and social status provides additional value over evaluating only an individual's 20MSRT score. Potential use-cases are, for example, the national or regional fitness monitoring systems where a large number of children and adolescents are tested (up to >90% of age-cohort). Resources for interventions are typically limited and necessary to be directed for correct individuals. The next steps to use this method in practice would be to train the final model with selected feasible variables and to collect independent test data that the model could be evaluated against. To reduce the number of variables, for example, to indicate PA, it is possible to employ a stepwise variable elimination method to RF to select only the best variable.[27]

It is, however, important to use ML methods and computational power robustly. The availability of ML libraries and computational power lead easily to data fishing. This means that a fair application of CV techniques must assess the generalisation ability of the models, and the risk of chance findings should be eliminated using permutation testing or other relevant techniques. In the present framework, these aspects of ML application have been considered carefully.

Strengths and limitations

The strengths of this study were the novel application for RF and the approach to predict individual fitness development in apparently healthy adolescents, the extensiveness of the variables in the data sample, robust analyses and measurements performed by educated professionals. Limitations include the 2-year duration of the study—more prominent changes could have potentially emerged with a longer follow-up period. The data sample was limited by its size (eg, n=50 in the lowest tertile in Task 2), possibly influencing prediction performance. There is also room for improvement in handling the importance of variables. For example, it is possible to employ a stepwise variable elimination method to RF to reduce the effect of multicollinearity in data. The study used a sample from an observational study. Despite the efforts, sampling bias might exist and affect the generalisability of the findings to the adolescent population.

Conclusion

With the ML approach, we could predict unfavourable future 20MSRT status based on 14–20 baseline characteristics and identify potential individuals for interventions. These promising findings support adopting a more holistic approach, taking physical and psychological and social factors into account in large-scale fitness monitoring systems. The ML algorithms used in this study are provided for future research.

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Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not required.

Ethics approval The original study setting was approved by the ethics committee of the University of Jyväskylä. Participants and their guardians delivered a signed informed consent. All measurements were carried out by trained personnel and in accordance with the Declaration of Helsinki.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Raw is agreed not to be shared with third parties. In other cases, data are available upon reasonable request. Please contact THT for data sharing.

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IV

PHYSICAL ACTIVITY, PHYSICAL FITNESS, AND SELF-RATED HEALTH: CROSS-SECTIONAL AND LONGITUDINAL ASSOCIATIONS IN ADOLESCENTS

by

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