JYU DISSERTATIONS 747

Iiris Kolunsarka

Developmental Associations of Physical Activity, Motor Competence, Perceived Motor Competence, Health-Related Fitness, and Weight Status through Adolescence

A 4-year Follow-up Study

UNIVERSITY OF JYVÄSKYLÄ
FACULTY OF SPORT AND
HEALTH SCIENCES

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ABSTRACT

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This dissertation investigated longitudinal associations among five variables: motor competence (assessed using the 5-leaps, throw-catch combination, and KTK subtests), perceived motor competence (assessed using a perceived sport competence questionnaire), health-related fitness (measured via the 20-meter shuttle run and push-up tests), physical activity (monitored with accelerometers), and body mass index (BMI) across the transition from early to middle adolescence, with participation in organized sports as a potential confounding factor. This dissertation consists of four original articles (I-IV) and a summary section. The data were collected from various regions in Finland over the period 2017 to 2021. The initial study population comprised 1 167 Finnish 5th grade students who were 11 years old in 2017. The conceptual model proposed by Stodden et al. (2008) served as the theoretical framework. The four studies applied advanced statistical methods, including latent growth curve, transition, and profile analyses. Study I revealed significant intra- and inter-individual variance in all five key variables. The results showed that a larger increase in BMI was correlated with a greater decline in MVPA and fewer improvements in cardiorespiratory fitness. Study II revealed relatively stable and distinct profiles among adolescents based on the five key variables. The adolescents in the different profiles shared similar characteristics, such as high actual and perceived competence, fitness, and physical activity. Study III showed over time that the adolescents exhibited varying levels of motor competence and that lower motor competence was associated with lower cardiorespiratory fitness and physical activity. Study IV found that dropout from organized sports was associated with a plateau in health-related fitness, emphasizing the importance of continued participation in physical activity. The overall findings offer valuable longitudinal insights into the interaction of variables closely associated with physical activity and physical health during adolescence. They provide a foundation for developing strategies to promote physical activity, improve fitness, and prevent overweight and obesity during this crucial stage of development.

Keywords: adolescents, development, cardiorespiratory fitness, muscular fitness, motor skills, weight development, MVPA, physical self-perception.

TIIVISTELMÄ (ABSTRACT IN FINNISH)

Kolunsarka, Iiris
Fyysisen aktiivisuuden, motorisen pätevyyden, koetun motorisen pätevyyden, fyysisen kunnon ja painon kehitys ja yhteydet murrosiässä: 4 vuoden seurantatutkimus
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Tässä väitöskirjassa tutkittiin pitkittäisiä yhteyksiä viiden muuttujan välillä murrosiässä: motorinen pätevyys (mitattiin vauhdittomalla 5-loikalla, heitto-kiinniotto-yhdistelmällä sekä KTK-osatesteillä), koettu motorinen pätevyys (mitattiin koetun liikunnallisen pätevyyden kyselyllä), fyysinen kunto (mitattiin 20-metrin viivajuoksulla ja punnerrustestillä), fyysinen aktiivisuus (mitattiin kiihtyvyysantureilla) ja kehon painoindeksi (BMI). Lisäksi tarkasteltiin organisoidun urheiluseuraharrastamisen yhteyttä kunnon ja painoindeksin kehitykseen. Väitöskirjassa hyödynnettiin vuosien 2017–2021 aikana eri puolilta Suomea kerättyä aineistoa, johon osallistui alun perin 1167 suomalaista 5. luokan oppilasta, jotka olivat 11-vuotiaita vuonna 2017. Väitöskirja koostuu neljästä alkuperäisartikkelista (I–IV) ja yhteenveto-osasta. Tutkimuksessa hyödynnettiin Stoddenin ym. vuonna 2008 esittämää käsitteellistä mallia. Tilastollisissa analyyseissä käytettiin edistyneitä menetelmiä, kuten kasvukäyrä-, siirtymä- ja profiilianalyysia. Osatutkimus I paljasti merkittävää yksilöiden välistä vaihtelua kaikissa päämuuttujissa. BMI:n jyrkempi nousu oli yhteydessä fyysisen aktiivisuuden jyrkempään laskuun sekä heikompiin parannuksiin kestävyyskunnossa. Osatutkimuksessa II havaittiin suhteellisen vakaat ja selkeät profiilit nuorten keskuudessa viiden päämuuttujan suhteen, joissa saman profiilin nuorilla oli yhteneviä piirteitä, kuten korkea motorinen ja koettu pätevyys, hyvä kunto ja korkea fyysinen aktiivisuus. Osatutkimus III osoitti, että suhteessa toisiinsa nuorten motoriset taidot vaihtelivat merkittävästi murrosiän aikana. Lisäksi heikompi motorinen pätevyys oli yhteydessä heikompaan kestävyyskuntoon ja vähäisempään fyysiseen aktiivisuuteen neljän seurantavuoden aikana. Osatutkimuksessa IV huomattiin, että urheiluseuraharrastuksen lopettaminen oli epäedullisesti yhteydessä fyysiseen kuntoon. Väitöskirjan havainnot tarjoavat arvokkaita näkemyksiä fyysisen aktiivisuuden ja siihen liittyvien muuttujien vuorovaikutuksesta murrosiässä. Näiden tulosten perusteella voidaan kehittää strategioita fyysisen aktiivisuuden edistämiseksi, kunnon parantamiseksi sekä ylipainon ja lihavuuden ehkäisemiseksi.

Avainsanat: murrosikä, kehitys, kestävyyskunto, lihaskunto, motoriset taidot, painon kehitys, reipas ja rasittava liikunta, koettu liikunnallinen pätevyys.

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In 2017, at the end of my bachelor years, my dear friend Sanna approached me in the university hallway and asked if I would be interested in taking on some paid work as a research assistant alongside my studies. She told me about the upcoming MOVE-study, led by Senior Lecturer Timo Jaakkola. Without much hesitation, I replied "Yes," unknowingly setting the stage for my current journey.

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Iiris Kolunsarka was responsible for planning the dissertation and drafting the articles. As the first author, she formulated the study questions, prepared the data for statistical analysis, conducted the analysis, and incorporated feedback and guidance from her co-authors throughout the research process and in making the final decisions. From 2017 to 2018, she assisted in the data collection, which she subsequently led from 2019 to 2021.

FIGURE

FIGURE 1 Development of movement skills. Adapted from Hulteen et al. (2018). 18
FIGURE 2 Conceptual model of motor development. Adapted from the original model of Stodden et al. (2008). EC = early childhood, LC = late childhood, MC = middle childhood. 27
FIGURE 3 Timeline of data collection and time points used in Studies I, II, III and IV. 43
FIGURE 4 Latent growth curve model. 48
FIGURE 5 Individual trajectories of A) BMI, B) MVPA, C) Perceived motor competence, D) Motor competence, and E) Cardiorespiratory fitness in Study I 53
FIGURE 6 Profile characteristics in Study II. 56
FIGURE 7 Standardized motor competence scores of the adolescents in each motor competence profile in Study III. 58
FIGURE 8 Development of MVPA in the low (red), moderate (blue) and high (green) motor competence profiles in Study III. 59
FIGURE 9 Development of cardiorespiratory fitness in the low (red), moderate (blue) and high (green) motor competence profiles in Study III. 59
FIGURE 10 Trajectories of cardiorespiratory fitness for each sport participation group (mean scores are presented) in Study IV. 62
FIGURE 11 Trajectories of muscular fitness for each sport participation group (mean scores are presented) in Study IV. 62
FIGURE 12 Trajectories of BMI for each sport participation group (mean scores are presented) in Study IV. 63

TABLE

TABLE 1	Associations between variables presented in the conceptual model of Stodden et al. (2008).	29
TABLE 2	Summary of variables and their measurements across studies.	47
TABLE 3	Five-step model for transition analyses. Adapted and modified from Nylund et al. (2007).	49
TABLE 4	Two-step model for auxiliary regression model. Adapted and modified from Asparouhov & Muthén (2021).	50
TABLE 5	Means, standard deviations and percentiles of MVPA, BMI and sport participation.	51
TABLE 6	Means and standard deviations of study variables in Study I	52
TABLE 7	Levels and slopes of parallel latent growth curves in Study I.	53
TABLE 8	Profile prevalences, the number of adolescents, and gender distribution over four time points on profiles in Study II.	54
TABLE 9	Descriptives for profiles at each time point in Study II	55
TABLE 10	Transition probabilities over four time points on profiles in Study II.	57
TABLE 11	Levels and slopes of MVPA and cardiorespiratory fitness for each motor competence profile in Study III.	58
TABLE 12	Descriptives of study variables in Study IV.	60
TABLE 13	Levels and slopes of cardiorespiratory fitness, muscular fitness, and BMI for each sport participation group in Study IV.	61

ABBREVIATIONS

AIC	Akaike Information Criterion
ABIC	Adjusted Bayesian Information Criterion
ALMR-LTR	Adjusted Lo-Mendell-Rubin likelihood ratio test
BIC	Bayesian Information Criterion
BMI	Body mass index
CI	Confidence interval
CFI	Comparative fit index
IOTF	International Obesity Task Force
KG	Kilogram
KTK	Körperkoordinationstest für kinder
M	Mean
m	Meter
Min	Minute
MLR	Robust full-information maximum likelihood
MVPA	Moderate-to-vigorous physical activity
n	Number
NCD	Non-communicable diseases
p	Significance probability
PHV	Peak height velocity
PSPP	Physical self-perception profile
RMSEA	Root mean square error of approximation
SD	Standard deviation
SE	Standard error
SRMR	Standardized root mean square residual
TLI	Tucker-Lewis Index
VO2max	Maximal oxygen consumption
WHO	World Health Organization
$\chi 2$	The model chi-square

CONTENTS

ABSTRACT
TIIVISTELMÄ (ABSTRACT IN FINNISH)
ACKNOWLEDGEMENTS
ORIGINAL PUBLICATIONS AND AUTHOR CONTRIBUTION
FIGURES AND TABLES
ABBREVIATIONS
CONTENTS

1 INTRODUCTION 13

2 REVIEW OF THE LITERATURE 16
2.1 Motor competence 16
2.1.1 Definition and assessments of motor competence 16
2.1.2 Development of motor competence 17
2.2 Perceived motor competence 20
2.2.1 Definition and assessment of perceived motor competence .. 20
2.2.2 Development of perceived motor competence 20
2.3 Health-related fitness 21
2.3.1 Definition and assessment of health-related fitness 21
2.3.2 Developmental perspective of health-related fitness 22
2.4 Physical activity 24
2.4.1 Definition and assessments of physical activity 24
2.4.2 Physical activity in adolescence 24
2.5 Weight status 25
2.5.1 Definition and assessment of weight status 25
2.5.2 Development of weight status during adolescence 26
2.6 A conceptual model hypothesizing the relationships among physical activity, motor skill competence, perceived motor skill competence, health-related fitness, and weight status........ 27
2.7 Empirical evidence for the associations between variables presented in the conceptual model of Stodden et al. (2008) 29
2.7.1 Associations between motor competence physical activity, health-related fitness, perceived motor competence and weight status. 30
2.7.2 Associations between physical activity and health-related fitness, perceived motor competence and weight status........ 34
2.7.3 Associations between weight status and health-related fitness and perceived motor competence 36
2.8 The rationale of the current study 38

3 DISSERTATION PURPOSE AND AIMS 41

4 MATERIALS AND METHODS 42
4.1 Study design and participants 42
4.2 Study ethics.. 43
4.3 Assessments.. 44
4.3.1 Motor competence.. 44
4.3.2 Perceived motor competence 45
4.3.3 Health-related fitness.. 45
4.3.4 Physical activity.. 45
4.3.5 Weight status 46
4.3.6 Organized sport participation.. 46
4.3.7 Maturation.. 46
4.4 Statistical analyses 47

5 OVERVIEW OF THE RESULTS.. 51
5.1 Developmental associations between motor competence, perceived motor competence, cardiorespiratory fitness, MVPA, and BMI from early to middle adolescence 52
5.2 Profiles of children based on their motor competence, perceived motor competence, cardiorespiratory fitness, MVPA and weight status, and the stability of their profile memberships over time....... 54
5.3 Motor competence profiles and their associations with trajectories of cardiorespiratory fitness and MVPA.. 57
5.4 Association of organized sport participation with health-related fitness.. 60

6 DISCUSSION 64
6.1 Main findings 64
6.2 Developmental associations of motor competence, perceived motor competence, health-related fitness, physical activity, and weight status from early to middle adolescence.. 65
6.3 Distinct movement profiles and their stability over time.................. 68
6.4 The role of motor competence for physical activity and cardiorespiratory fitness 71
6.5 The role of sport participation on health-related fitness and weight status.. 73
6.6 Limitations 76

7 CONCLUSIONS, PRACTICAL IMPLICATIONS AND FUTURE DIRECTIONS.. 77
7.1 Conclusions.. 77
7.2 Practical implications 79
7.3 Future research.. 81

YHTEENVETO (SUMMARY IN FINNISH) 83

REFERENCES.. 88

APPENDICES

ORIGINAL PAPERS

1 INTRODUCTION

Obesity and physical inactivity are significant global health concerns (GBD 2015 Obesity Collaborators, 2017; WHO, 2018; 2022; Katzmarzyk et al., 2022). The prevalence of overweight and obesity has dramatically increased worldwide in just one generation. Although the increase in the prevalence of childhood obesity in some high-income countries may be leveling off, it remains historically high and is expected to put a strain on future healthcare services (Lobstein et al., 2015; Ng et al., 2014; NCD-RisC, 2017). The main factors contributing to the increasing rates of overweight and obesity are changes in global food systems and dietary habits, along with sedentary lifestyles and insufficient physical activity (Swinburn et al., 2011; Franco et al., 2013; Blüher, 2019; Popkin et al., 2020). Changes in social and environmental factors have also contributed to the current insufficient levels of physical activity found among both children and adults (Franco et al., 2013; Guthold et al., 2018; 2020; Lieberman et al., 2021). Overall, the global burden of physical inactivity is significant, serving as a significant modifiable risk factor for non-communicable diseases (NCDs) and mental health conditions (Katzmarzyk et al., 2022). Moreover, the decline in physical activity among children and adolescents, coupled with an increase in overweight and obesity rates, has resulted in a decreasing trend in physical fitness over the past few decades (Tomkinson et al., 2018; Masanovic et al., 2020; Huotari et al., 2023). This is a cause for concern, given the strong inverse and independent association between adolescents' physical fitness and their risk of future disease outcomes, including premature mortality, in adulthood (Högström et al., 2016; García-Hermoso et al., 2019; García-Hermoso et al., 2020; Henriksson et al., 2021). A recent study estimated that without effective action to increase physical activity levels by 2030, as outlined in the World Health Organization's (WHO) Global Action Plan for Physical Activity (WHO, 2018), countries will face significant costs in terms of preventable new cases of NCDs (Santos et al., 2023). Back in 2013, the estimated cost of global inactivity was 53.8 billion international dollars, with more than half of this cost being covered by the public sector (Ding et al., 2016). Hence, the promotion of physical activity is of paramount importance.

The current guidelines recommend that children and adolescents should engage in at least 60 minutes of moderate-to-vigorous physical activity (MVPA) each day (Bull et al., 2020). However, a significant current concern is that approximately 80% of adolescents aged 11–17 worldwide do not meet this recommendation (Guthold et al., 2020). This is particularly troubling as the foundation for a physically active lifestyle is primarily established during childhood (Stodden et al., 2008; Sawyer et al., 2012; Aaltonen et al., 2015), and physical activity and physical fitness patterns tend to persist from adolescence into adulthood (Telama et al., 2014; Fraser et al., 2023). The physical activity guidelines for children and adolescents focus not only on preventing NCDs and premature mortality but also on improving fitness, developing coordination and movement control, and promoting a healthy body weight (Bull et al., 2020). In general, physical activity declines as adolescents progress through their teenage years (Farooq et al., 2020). This decline is often accompanied by a peak in dropout rates from organized sports (Crane & Temple, 2015). However, it is essential to recognize that not all adolescents follow the same patterns of physical activity (Kwon et al., 2015; Lounassalo et al., 2019). On the contrary, some adolescents are able to maintain a high level of physical activity (Kwon et al., 2015). This underscores the necessity for analytical methods that are able not only to capture the variability in how individuals change their physical activity levels over time but also help identify the factors associated with these diverse patterns. Understanding the factors associated with physical activity behavior and the pathways leading to physical inactivity and poor physical fitness as they unfold during development (Stodden et al., 2008) is crucial. Since most interventions have failed to promote sustainable changes in physical activity behaviors among adolescents (van Sluijs et al., 2021), knowledge of these factors may help in designing more effective strategies to promote physical activity and overall health.

In 2008, Stodden and his colleagues published a conceptual model that describes the dynamic association between factors related to physical activity. The model includes motor competence, perceived motor competence, health-related fitness, physical activity, and weight status. The conceptual model positions motor competence as a cornerstone for physical activity from middle childhood (7 years) onwards (Stodden et al., 2008). Motor competence, also referred to as fundamental movement skills, serves as a foundation for engaging in physical activities, enabling individuals to perform various movements and tasks (Goodway et al., 2021). Unfortunately, a recent systematic review showed that while younger children worldwide demonstrated average levels of motor competence, children in middle and late childhood (6–10 years) had below-average levels of fundamental movement skills (Bolger et al., 2021). It should also be noted that although childhood is a crucial period for developing motor skills through play and structured physical activities, such as organized sports, children vary widely in their skill development (Coppens et al., 2019; Rodrigues et al., 2016). This variation can be attributed to differences in opportunities, abilities, and support (Morgan et al., 2013; Goodway et al., 2021). According to the conceptual model (Stodden et al., 2008), as children grow older and become more aware of their motor skill levels (True et al., 2017), those with lower motor skills may lack both the skills and the confidence to engage in physical activity (Babic et al., 2014). Thus, due to increased awareness of their perceived limitations and potential for success some children may disengage from physical activities. This, in turn, may lead to less favorable development of their health-related fitness (Babic et al., 2014). However, the most recent systematic review revealed that a significant proportion of the evidence supporting these associations has been based on cross-sectional data (Barnett et al., 2022). At the same time, the numerous proposed longitudinal pathways are primarily theoretical and lack empirical support (Barnett et al., 2022). Moreover, while many previous longitudinal studies have focused on pre-adolescent children, adolescence is a critical period for shaping long-term activity habits (van Sluijs et al., 2021). Understanding the complex relationships between the development of motor competence, perceived motor competence, health-related fitness, physical activity, and weight status during adolescence can offer valuable insights for designing enduring and effective interventions aimed at promoting an active lifestyle.

The conceptual model developed by Stodden et al. (2008) was used in this dissertation research to explain the reciprocal and dynamic relationships between motor competence, perceived motor competence, health-related fitness, physical activity, and weight status during early adolescence (11-15 years of age). Moreover, participation in organized sport was considered a confounding factor due to its strong association with the variables presented and the contextual framework in which physical activity typically takes place during early adolescence (Hebert et al., 2015, Kokko et al., 2019). Furthermore, to gain a better understanding of developmental pathways in the context of individual variations, person-oriented methods were employed. Given that each adolescent's development is unique, this approach enables intra- and inter-individual differences to be captured over time. In sum, this dissertation research report is based on four original articles (I-IV) and a summary section. Together, the four studies extend earlier findings by investigating the developmental associations between the five key variables and contribute significantly to the literature on adolescents' physical activity and health. The insights gained from this research have potential practical applications, especially in the development of strategies aimed at promoting physical activity, improving fitness, and preventing overweight and obesity in adolescents.

2 REVIEW OF THE LITERATURE

2.1 Motor competence

2.1.1 Definition and assessments of motor competence

Motor skill is a general term that refers to the ability of the neuromuscular system to control muscle movements with the intent of performing specific motions or actions (Magill & Anderson, 2017). These skills can be categorized into fine motor skills, which involve movements of the small muscle groups, and gross motor skills, which involve movements of the larger muscle groups (Goodway et al., 2021). Motor skill learning, also known as motor skill acquisition, is the process through which repeated practice and interactions with the environment lead to movements being executed effortlessly (Willingham, 1998). This process involves enhancing the speed and accuracy of movements, which leads to improved movement consistency, efficiency, and automation (Magill & Anderson, 2017). Through repeated practice, individual movement performances became more consistent, although not identical (Shmuelof et al., 2012; Willingham, 1998). The acquisition of complex motor tasks leads to structural changes in cortical and subcortical structures in the human brain (Dayan & Cohen, 2011; Hardwick et al., 2012). These changes, accompanied by neuromuscular adaptation, contribute to lasting improvements in the temporal and spatial accuracy of movements (Shmuelof et al., 2012). Once motor skills are acquired and consolidated, they can be retained over extended periods of time. Thus, they can be recalled and repeated more easily than wholly new tasks (Doyon & Benali, 2005).

Fundamental movement skills are basic movement patterns that involve different body parts and are utilized in daily activities (Goodway et al., 2021). They are essential for individuals to participate in various physical activities, as they serve as the foundation for more complex and specialized movements, such as sports skills, fine motor skills, and complex motor tasks. Hence, they provide the basis for the skills required in a wide variety of play, games, and sports activities (Haubenstricker & Seefeldt, 1986; Clark & Metcalf, 2002). Fundamental movement skills are typically classified into three categories: locomotor, object control, and balance skills. Locomotor skills, such as running, hopping, skipping, and sliding, involve moving the body through space. In turn, object control skills, such as throwing, catching, kicking, and bouncing, consist of manipulating and projecting objects (Goodway et al., 2021). Lastly, balance skills can be defined as the capacity to perceive changes in the alignment of body parts that affect one's equilibrium and to adapt to these alterations promptly and precisely with the right corrective actions (Goodway et al., 2021). 'Motor competence' is a globally understood term that describes goal-directed and coordinated fundamental human movement skills involving interactions between the neuromuscular system and the environment (Stodden et al., 2008; Robinson et al., 2015; Barnett et al., 2022). As there is no single universally accepted definition of motor competence, and multiple terms are used in the literature to encompass various aspects of human movement skills (e.g., motor proficiency, motor performance, fundamental movement/motor skill, motor ability, and motor coordination) (Logan et al., 2018), motor competence was the term used in this dissertation research to describe goal-directed and coordinated fundamental human movement skills, such as leaping, jumping, balancing, throwing, and catching an object.

Motor competence assessments commonly rely on either product-oriented or process-oriented scoring approaches (Cools et al., 2009; Bardid et al., 2019). These approaches provide different perspectives on evaluating motor skills and can offer complementary information (Ré et al., 2018). Product-oriented scores are quantitative outcomes, such as the distance hopped or the number of throws that succeed in hitting a target, irrespective of the quality of the movement performed. Conversely, process-oriented scoring is based on evaluating movement execution quality and involves assessing a predetermined list of criteria that determine whether specific techniques are present or absent when a particular movement is performed (Hulteen et al., 2020; Bardid et al., 2019). This dissertation exclusively used product-oriented measures, primarily due to the high number and advanced age of the participants and time constraints imposed by school curricula.

2.1.2 Development of motor competence

Motor development refers to changes in movement abilities and underlying processes over the lifespan (Goodway et al., 2021). Motor development begins with reflexive (involuntary and subcortically controlled) movements and continues with rudimentary movements (the first forms of voluntary movements) (see Figure 1) (Adolph & Franchak, 2017). During the first two years of life, heredity plays a significant role in motor development, which can be either promoted or hindered it by the environment (Clark & Metcalf, 2002; Adolph & Franchak, 2017; Goodway et al., 2021; Zi et al. 2023). In early childhood (2–6 years of age), children have the opportunity to learn fundamental movement skills through play and games that they enjoy (Goodway et al., 2021). As play is to children what work is to adults, early childhood is considered a critical period for promoting fundamental movement skills (Clark & Metcalfe, 2002). Later in childhood and adolescence, fundamental motor patterns will provide the basis for context-specific movements and overall motor skillfulness (Haubenstricker & Seefeldt, 1986; Clark & Metcalfe, 2002). The concept of a motor proficiency barrier, first presented by Seefeldt et al. (1980), suggests that individuals who lack fundamental movement skills may have difficulty learning advanced skills and participating in physical activities (De Meester et al., 2018; Brian et al., 2020; V. P. Lopes et al., 2021).

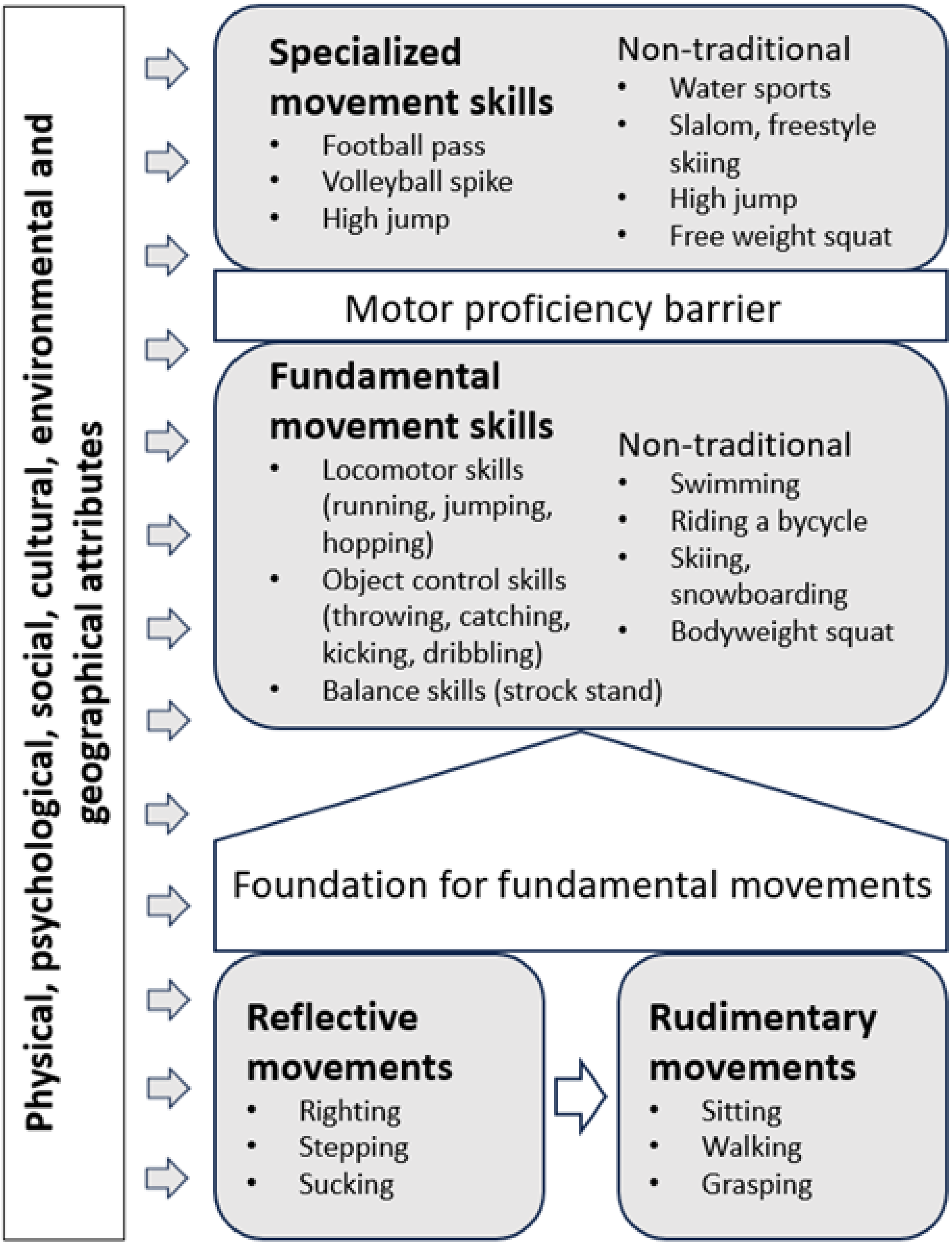


FIGURE 1 Development of movement skills. Adapted from Hulteen et al. (2018).

Motor development is a sequential and cumulative process influenced by a combination of physical, psychological, and social factors (Magill & Anderson, 2017). Physical factors, such as genetics (Missitzi et al., 2013; Zi et al., 2023), sex (Barnett et al., 2010; 2016), body composition (V. P. Lopes et al., 2020), and maturation, have been identified as contributors to motor development (Clark & Metcalfe, 2002; Goodway et al., 2021). However, gender roles, parenting styles, societal stereotypes, opportunities for movement experiences, encouragement, motivation, demographic factors, and social influences all contribute to the development of motor skills (Malina et al., 2004; Barnett et al., 2016; Adolph & Hoch, 2019; Goodway et al., 2021; Anderson et al., 2021). For example, a meta-analysis conducted by Barnett et al. (2016) provided strong evidence that boys exhibit superior object control skills in comparison to girls. Moreover, another meta-analysis indicated that this difference becomes apparent as early as at three years of age and tends to intensify thereafter (Zheng et al., 2022). This disparity could potentially stem from evolutionary/biological differences (Butterfield et al., 2012) and social factors, such as increased encouragement for boys' participation in physical activities (Telford, Telford, Olive et al., 2016; Kretschmer et al., 2023), especially those that involve ball skills, such as football and ice hockey (Hannon et al., 2009). Socio-cultural and geographic factors create an environment that either supports or constrains the development of motor competence in individuals (Clark & Metcalfe, 2002; Barnett et al., 2016; Hulteen et al., 2018; Goodway et al., 2021).

Most children are expected, owing to an increasing number of experiences and practice, to acquire fundamental movement skills and improve motor competence as they age (Barnett et al., 2016). Motor skills do not automatically develop with age, but rather are learned through active engagement in play, games, and a variety of physical activities (Clark & Metcalfe, 2002; Morgan et al., 2013; Goodway et al., 2021). Therefore, disparities arise between individuals who have access to enriched and varied movement experiences and those who have limited opportunities for movement (Morgan et al., 2013; Rodrigues et al., 2016). While all children have the potential to develop motor competence through participation in context-specific free play and structured physical activities (Clark & Metcalfe, 2002; Goodway et al., 2020), it is important to acknowledge that not all children reach the same level of proficiency (Rodrigues et al., 2016; Coppens et al., 2019). This discrepancy is concerning, since fundamental movement skills provide the building blocks for later, more specific movements in various contexts (Clark & Metcalfe, 2002). These skills are essential for engaging in a wide range of physical activities throughout life (Stodden et al., 2008). Overall, the development of childhood motor competence has a significant association with physical activity behaviors (V. P. Lopes et al., 2011; Aaltonen et al., 2015), physical fitness (Utesch et al., 2019), weight development (Rodrigues et al., 2016), and health markers (Pombo et al., 2023).

2.2 Perceived motor competence

2.2.1 Definition and assessment of perceived motor competence

As originally proposed by Shavelson et al. (1976), general self-concept is a person's perception of themselves. It is a hierarchical structure consisting of four domains: academic, social, emotional, and physical self-concept (Shavelson et al., 1976). Physical self-concept can be further divided into physical abilities and physical appearance (Shavelson et al., 1976) or, as proposed by Fox and Corbin (1989), into four dimensions: sports competence, body attractiveness, physical strength, and physical condition. Within the realm of physical abilities or sports competence, a crucial aspect is the perception of one's motor competence. This term is often used interchangeably with perceived sports competence, perceived physical competence, and perceived athletic competence (De Meester et al., 2020). Estevan and Barnett (2018) argue that the domain of perceived motor competence corresponds to the domain of perceived sport/athletic competence, which Fox and Corbin (1989) proposed is a domain of physical self-concept. Perceived motor competence reflects an individual's beliefs about their own physical abilities (Estevan & Barnett, 2018). These beliefs are shaped by individuals' experiences with their environment and how they interpret these (Shavelson et al., 1976). In the context of physical activity, perceptions of motor/sport competence are generally regarded as indicators of individuals' confidence in performing sports, of their excelling in sports, and their readiness to acquire new skills (Harter, 1982). Notably, these perceptions may play a significant role in determining individuals' engagement in physical activity (Babic et al., 2014), as high perceived competence may promote motivation to engage in physical activities (Welk, 1999). Individuals' self-perceptions of their sport/motor competence are commonly measured with questionnaires (Estevan & Barnett, 2018). In this dissertation research, the term 'perceived motor competence' is used to refer to an individual's perception of his/her sport/physical competence while acknowledging that this measure is not aligned with the measures of motor skill competence utilized in the study but instead encompasses a broader construct (physical self-perception).

2.2.2 Development of perceived motor competence

Perceived competence is influenced by a variety of factors, including both external factors, such as social influence and adult feedback, and internal factors, such as personal standards of success and failure (Harter, 1978). However, in the developmental context, it is important to recognize that young children's perceptions of their own competence may not yet be realistic (Harter, 1999). Young children may confuse their desires to be competent with reality and may not yet possess the ability to use social comparison to accurately assess their own competence (Horn & Weiss, 1991). The ability to self-perceive improves as cognitive development progresses (Harter, 1999). This has led to the hypothesis that as children age, their perceptions of their motor competence align more accurately with their actual motor competence (Stodden et al., 2008). Consequently, children with lower motor competence are more likely to have less favorable perceptions of their abilities, which may lead them to avoid participating in physical activities (Babic et al., 2014). This action, in turn, may further hinder the development of their motor competence (Stodden et al., 2008). However, a recent meta-analysis by De Meester et al. (2020) showed that while the associations between actual and perceived motor competence were low to moderate, the strength of the association did not differ by age or developmental status, although the researchers noted that fewer studies focused on older age groups. Moreover, age moderation in the meta-analysis was determined using the mean ages of the study (sub)samples. Since most studies included participants with a wide age range, any potential age-related effects were already accounted for within each study (sub)sample (De Meester et al., 2020). For instance, in their cohort study, True et al. (2017) found that the strength of the association between perceived and actual motor competence increased across age groups. This finding supports the hypothesis that as children age, their ability to comprehend and accurately assess their own competence improves (Harter, 1999). Girls' and boys' perceptions of their own physical competencies may also differ (Lirgg, 1991). For example, research has shown that boys levels of perceived competence tend to be higher than those of girls (Rose et al., 2015). Boys are also more likely to overestimate and girls to underestimate their object control skills (Pesce et al., 2018). Such gender differences may be influenced by societal expectations (Chalabaev et al., 2013) as well as variation in actual motor competence (Barnett et al., 2016). The development of perceived motor competence thus plays a vital role in fostering motivation and self-confidence to engage in physical activities (Babic et al., 2014).

2.3 Health-related fitness

2.3.1 Definition and assessment of health-related fitness

Bouchard and Shepard (1994) defined health-related fitness as a set of physical attributes that contribute to overall health. These attributes include cardiorespiratory fitness, muscular fitness, joint flexibility, and body composition. Cardiorespiratory fitness (also known as cardiovascular fitness, aerobic fitness, aerobic capacity, or cardiorespiratory endurance) refers to the capacity of the circulatory and respiratory systems to deliver oxygen to the skeletal muscle mitochondria for energy production needed during physical activity (Caspersen et al., 1985; McArdle, 2015; Raghuveer et al., 2020). Cardiorespiratory fitness is measured as maximal oxygen consumption (VO2max), which represents the maximum amount of oxygen a person can intake during exercise (McArdle, 2015). VO2max can be determined through a maximal test such as the cardiopulmonary exercise test, which measures respiratory gases (McArdle, 2015; Raghuveer et al., 2020). Alternatively, VO2max can be estimated through a submaximal test, such as the 20-meter shuttle run test. This test utilizes equations that have been validated against cardiopulmonary exercise tests (Léger & Lambert, 1982). However, it is important to note that submaximal tests that require moving the body through space, such as the 20-meter shuttle run test, are largely influenced by fat mass which, although not contributing to VO2max, influences aerobic performance (Welsman & Armstrong, 2019). Muscular fitness can be categorized into two primary components: muscular strength and muscular endurance (Caspersen et al., 1985; Enoka, 2015). Muscular strength refers to the muscles' capacity to generate external force, while muscular endurance refers to their ability to repeatedly perform work against resistance and avoid fatigue (Caspersen et al., 1985; Enoka, 2015). Muscular fitness can be measured as one maximal effort, such as grip strength, or as the number of sub-maximal repetitions, such as push-ups, performed during a fixed period of time (Enoka, 2015). Joint flexibility refers to the ability of joints to move through their full range of motion and can be assessed by measuring or evaluating the range of motion (Caspersen et al., 1985). In this dissertation research, cardiorespiratory fitness was measured using the 20-meter shuttle run test, while acknowledging that it is not a direct measure of VO2max and is influenced by factors such as fat mass and locomotor skills (Welsman & Armstrong, 2019). Muscular fitness was assessed using the push-up test, although it is important to note that this measurement can also be influenced by fat mass (Ervin et al., 2014). Additionally, the push-up test may serve as an indicator of muscle strength for certain adolescents, while for others it may reflect muscle endurance, depending on their relative strength levels. In the present research, flexibility was not measured. Therefore, the term "health-related fitness" refers specifically to cardiorespiratory and muscular fitness. Body composition, in turn, was assessed using BMI and is discussed as a separate aspect of health in this dissertation.

2.3.2 Developmental perspective of health-related fitness

Cardiorespiratory fitness undergoes significant development throughout childhood and especially during adolescence. This development is driven by morphological and physiological changes stimulated by growth and maturation (Malina et al., 2004; Armstrong and Welsman, 2019b; Raghuveer et al., 2020). These changes include an increase in lean body mass and enhanced function of heart, lungs and blood vessels that lead to improvements in the body's capacity to utilize and transport oxygen (Armstrong & Welsman, 1994; Malina et al., 2004; McArdle, 2015; Armstrong & Welsman, 2019a; Armstrong & Welsman, 2020). Moreover, the development of cardiorespiratory fitness is influenced by a range of individual factors, including genetics (Bouchard et al., 2011), the timing of maturation, and physical activity, which can all vary among individuals (Raghuveer, 2020). Notably, boys tend to consistently demonstrate higher levels of cardiorespiratory fitness than girls, with this difference becoming more pronounced around the age of 12 (Tomkinson et al., 2018). This disparity continues to widen as children move through adolescence, primarily due to the increased accumulation of muscle mass in boys following puberty (Armstrong & Welsman, 2019b). In contrast, increases in relative body fatness in girls seem to hinder improvements in cardiorespiratory fitness test scores (Malina et al., 2004). In addition to the effects of growth and maturation, cardiorespiratory fitness can be further improved through physical activity (Lin et al., 2015; Raghuveer et al., 2020). This factor may contribute to the higher fitness levels observed in boys even before puberty (Tomkinson et al., 2018), as they tend to engage more than girls in physical activities of moderate to vigorous intensity (Kretschmer et al., 2023). Improvement in cardiorespiratory fitness depends on the duration, intensity, and frequency of physical activity (McArdle, 2015). Frequent and vigorous physical activity of sufficient duration induces physiological changes that promote the body's capacity to deliver and use oxygen for energy production (McArdle, 2015). However, these changes are not permanent; instead, they are progressively lost when the duration, frequency, or intensity of training is reduced (McArdle, 2015; Spiering et al., 2021). Similarly, muscular fitness undergoes significant development throughout childhood and adolescence and is influenced by morphological and physiological changes that occur during growth and maturation. Muscle mass increases by about 90% in boys and 40% in girls between the ages of 11 and 16 (Malina et al., 2004; Armstrong & Welsman, 2019c). While muscular fitness is expected to increase throughout adolescence, it is also influenced by genetics (Schutte et al., 2016) and exercise (Folland & Williams, 2007). Muscular fitness can be enhanced through progressive strength training, which stimulates physiological changes such as muscle hypertrophy and improvements in neuromuscular activation (Folland & Williams, 2007). However, the changes in cardiorespiratory and muscular fitness induced by physical activity are not permanent; instead, they are progressively lost when the duration, frequency, or intensity of training is reduced (McArdle, 2015; Spiering et al., 2021). Health-related fitness tracks from childhood to adulthood (Fraser et al., 2017; Fraser et al., 2023), emphasizing the significance of the foundational groundwork laid during childhood. Moreover, cardiorespiratory fitness, especially, has been shown to be a powerful marker of adolescents' health (Ruiz et al., 2016; Raghuveer et al., 2020). For example, a meta-analysis conducted by Ruiz et al. (2016) found that children with low cardiorespiratory fitness are at a higher risk for developing cardiovascular disease. Furthermore, a recent meta-analysis by García-Hermoso et al. (2020) suggested that enhancing fitness levels in young individuals may be linked to maintaining a healthy weight and reducing cardiometabolic risk in the future.

2.4 Physical activity

2.4.1 Definition and assessments of physical activity

Caspersen et al. (1985) defined physical activity as "... any bodily movement produced by skeletal muscles that results in energy expenditure." Physical activity refers to all types of movement in different settings, including leisure time, schools, sports clubs, and commuting to school and leisure activities (Caspersen et al., 1985; WHO, 2018; Bull et al., 2020). Physical activity can be categorized based on its duration, quality, frequency, and intensity (Bull et al., 2020). Intensity refers to the level of metabolic energy demand placed on the body (Caspersen et al., 1985). The intensity of physical activity can be classified into three main categories: light, moderate, and vigorous. These categories are determined based on multiples of the resting metabolic equivalent (MET) (Haskell et al., 2007). MET is a widely used physiological model that provides a straightforward method for estimating the energy expenditure of physical activities as multiples of the resting metabolic rate (1 MET). Light physical activity refers to any activity during waking hours that is not sedentary and requires less than 3.0 METs. Moderate physical activity is defined as any activity with a metabolic equivalent of task (MET) value between 3.0 and 5.9, while vigorous physical activity refers to any activity with a MET value of 6.0 or higher. These categories provide a standardized way to gauge the intensity of different activities in relation to energy expenditure at rest (Haskell et al., 2007). The quantification and evaluation of physical activity levels and intensities can be accomplished through various methods, including self-reported questionnaires, diaries, and the use of objective devices such as accelerometers, heart rate monitors, and pedometers (Sylvia et al., 2014). Nonetheless, studies have shown a correlation between children's self-reported and device-measured physical activity, ranging from low to moderate (LeBlanc & Janssen, 2010; Marasso et al., 2021). In comparison to data measured by devices, children often tend to overestimate their self-reported levels of physical activity (LeBlanc & Janssen, 2010). In this dissertation, physical activity was measured using accelerometers.

2.4.2 Physical activity in adolescence

MVPA is commonly recommended for its health benefits (Bull et al., 2020). According to the World Health Organization (Bull et al., 2020) and the Finnish Ministry of Education and Culture (2021) recommendations, children and adolescents should engage in 60 minutes or more of MVPA each day. However, data from school-based surveys in 146 countries showed that approximately 80% of adolescents aged 11–17 worldwide fail to meet the current recommendation (Guthold et al., 2020). There is substantial evidence documenting a decline in physical activity as children get older (Corder et al., 2016; Farooq et al., 2020; van Sluijs et al., 2021; Husu et al., 2023). For instance, results from the latest Finnish national LIITU study (Husu et al., 2023) demonstrated that 66% of adolescents aged 11 and 91% of adolescents aged 15 did not meet the current recommendations for physical activity when measured with accelerometers. Several studies have shown that boys are consistently more active than girls (van Sluijs et al., 2021; Husu et al., 2023; Kretschmer et al., 2023). However, a recent empirical study by Kretschmer et al. (2023) revealed that although boys had higher mean levels of MVPA, their activity patterns exhibited greater variability. In contrast, the activity levels of girls were concentrated around median volumes of MVPA (Kretschmer et al., 2023). Nevertheless, it is important to acknowledge that children exhibit diverse trajectories of physical activity (Lounassalo et al., 2019). For instance, some individuals consistently demonstrate low levels of physical activity throughout adolescence, while others maintain a consistently high level of physical activity (Kwon et al., 2015; Farooq et al., 2020).

Adolescence is a stage of development characterized by significant physical, psychological, and social changes (van Sluijs et al., 2021). These changes include maturation, increased independence, identity formation, and the establishment of social relationships outside of the family (Backes et al., 2019). All these factors have the potential to impact physical activity behavior (van Sluijs et al., 2021). Furthermore, during the transition from childhood to adolescence, children develop an increased awareness of their competencies and may choose to disengage from activities in which they perceive a lack of success (Craggs et al., 2011). These actions may have long-term consequences, as research indicates that physical activity tends to persist from adolescence to adulthood (Telama et al., 2014; Hayes et al., 2019). It is worth noting that a large proportion of children in the Western world participate in organized sports (Eime et al., 2016; Kokko et al., 2019). This participation is associated with higher and more intense levels of physical activity (Telford, Telford, Cochrane et al., 2016; Kokko et al., 2019). However, the dropout rate from organized sports significantly increases during adolescence (Crane & Temple, 2015), which may contribute to declines in overall physical activity.

2.5 Weight status

2.5.1 Definition and assessment of weight status

Weight status refers to the classification of an individual's body weight according to specific criteria (WHO, 1995). Typical categories include underweight, normal weight, overweight, and obesity (WHO, 2022). Overweight and obesity refer to an excess amount of body fat (WHO, 1995; 2022). Obesity is recognized as one of the key risk factors for many NCDs (WHO, 2014; GBD Obesity Collaborators, 2015). Assessing fat mass, a component of body composition, can be done through various methods such as dual-energy x-ray, isotope dilution, underwater weighing, and portable techniques like bioimpedance and ultrasound (Thibault et al., 2012). However, for large-scale assessments, calculating BMI using anthropometric measurements is the simplest, quickest, and most cost-effective approach (Ng et al., 2014; Nuttall, 2015). BMI is a numerical value calculated by dividing a person's body mass (in kilograms (kg)) by the square of their height (in meters (m)). These numeric values are then used to determine weight status (WHO, 1995). For instance, according to the WHO in 2022, being overweight is defined as having a BMI of 25 or higher, while obesity is defined as having a BMI of 30 or higher. However, these fixed classifications are not appropriate for children, as their BMI changes significantly with age (Cole et al., 2000). Instead, there are national and international cutoff points specifically designed to assess weight statuses in children and adolescents (Cole & Lobstein, 2012). For example, in 2000, The International Obesity Task Force (IOTF) published international BMI cut-off points for overweight and obesity in children. These cut-offs, which were extended in 2012 by Cole & Lobstein, are sex- and age-specific and are linked to adult cut-off points (Cole et al., 2000). Although BMI is not an accurate measure of the quantity of body fat, it continues to be widely used in population-based studies and plays a significant role in shaping public health policies due to its simplicity (Ng et al., 2014; Nuttall, 2015; WHO, 2021; 2022). In this dissertation research, BMI was the method selected for evaluating the weight development and weight status of adolescents.

2.5.2 Development of weight status during adolescence

All children, owing to their growth and physical maturation, are expected to increase in weight as they age; however, the rate of change varies across individuals (Tanner & Whitehouse, 1976). The pathogenesis of overweight and obesity is multifactorial, complex, and influenced by a genetic predisposition for weight gain (Oussaada et al., 2019). However, the main reason for the excessive accumulation of fat mass is an ongoing imbalance between the total energy intake (calories consumed) and the total energy expenditure (calories burned through physical activity and metabolism) (Heymsfield & Wadden, 2017). This imbalance is influenced by obesity-related behaviors, such as physical activity, sedentary behavior, and diet (Blüher, 2019). These behaviors are often established in childhood and tend to persist into adulthood (Craigie et al., 2011; Sawyer et al., 2012; Hayes et al., 2019). However, the risk of childhood overweight appears to start early (Cunningham et al., 2014), even before the age of 2 years (Glavin et al., 2014). Globally, in developed countries, one out of five adolescents are overweight or obese (Ng et al., 2014). In Finland, 29% of boys and 20% of girls aged 13 to 16 have been classified as overweight or obese (THL, 2023). Research suggests that adolescents' weight status is unlikely to improve as they transition into young adulthood (Patton et al., 2011). Furthermore, the most rapid increase in the prevalence of obesity occurs after adolescence, specifically between the ages of 20 and 40 (Ng et al., 2014). Thus, prioritizing the promotion of healthy behaviors in childhood and adolescence becomes crucial in preventing overweight and obesity in the population.

2.6 A conceptual model hypothesizing the relationships among physical activity, motor skill competence, perceived motor skill competence, health-related fitness, and weight status

Several theoretical models emphasize the importance of developing motor competence throughout the lifespan. These models include those by Seefeldt (1980), Clark and Metcalfe (2002), Stodden et al. (2008), and Hulteen et al. (2018). All four models emphasize the importance of learning to move as a necessary skill for physical activity. In 1980, Seefeldt also introduced the concept of a "motor skill proficiency barrier." This concept suggests that individuals who fall below this threshold may encounter greater difficulties in acquiring advanced motor skills, thereby making their participation in games and sports more challenging. In line with this idea, Clark and Metcalf (2002) proposed the concept of motor development, using a metaphor of learning to climb a mountain. They emphasized that it is a sequential and cumulative process that takes years to master. Furthermore, motor development is influenced by the skills and abilities of an individual, as well as the context and amount of practice. Thus, to climb higher (i.e., learn context-specific and skillful movements to be used in sports and lifetime activities), one must first acquire the fundamental movement skills (Clark & Metclaf, 2002). In 2008, Stodden and his colleagues published a conceptual model that describes the role of motor skill competence in promoting physical activity (see Figure 2).

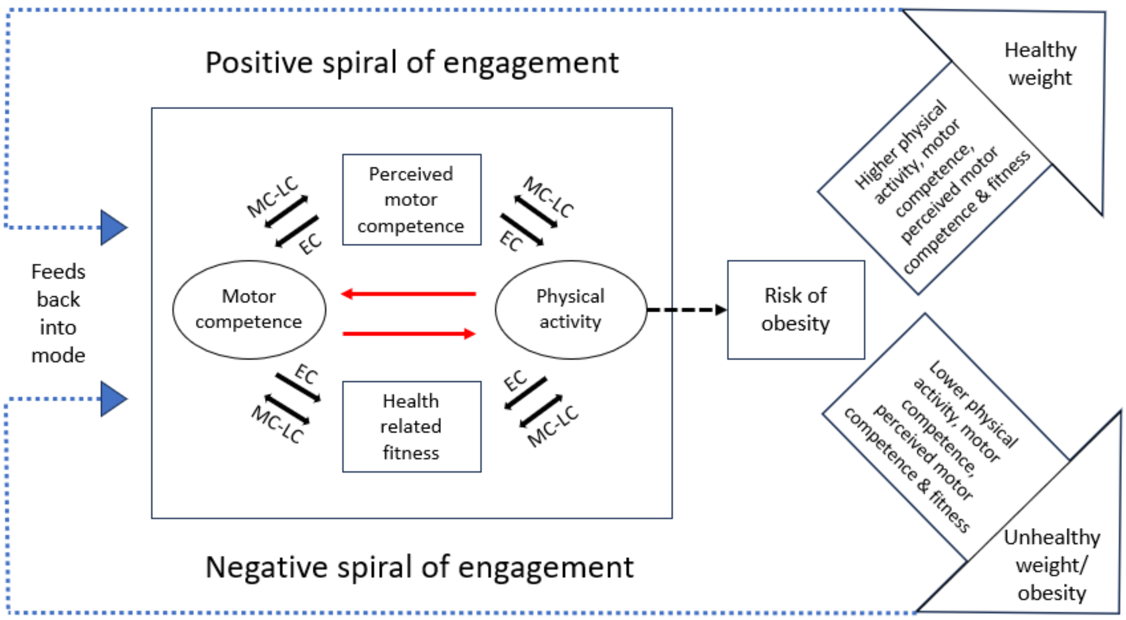


FIGURE 2 Conceptual model of motor development. Adapted from the original model of Stodden et al. (2008). EC = early childhood, LC = late childhood, MC = middle childhood.

The conceptual model suggests that motor competence, perceived motor competence, health-related fitness, physical activity, and weight status interact in a complex and dynamic manner, forming a vicious cycle that can either promote or hinder the development of a physically active lifestyle and healthy weight status in children. Systematic reviews were conducted to examine empirical evidence for this conceptual model, first by Robinson et al. (2015), and then by Barnett et al. (2022).

The conceptual model proposed by Stodden et al. (2008) suggests that motor competence acts as a driving force for physical activity, particularly in middle and late childhood. However, the evidence for this phenomenon is not strong (Barnett et al., 2022). While it is evident that a positive relationship exists between motor competence and physical activity (Robinson et al., 2015; Logan et al., 2015; Lubans et al., 2010; Stodden et al., 2008), a recent systematic review by Barnett et al. (2022) found no evidence for a causal longitudinal pathway from motor competence to physical activity. However, the conceptual model of Stodden et al. (2008) suggests that children who possess higher motor competence are more likely to actively engage in a variety of physical activities, such as sports and games, due to their broader range of motor skills (Seefeldt, 1980; Clark & Metcalf, 2002; Brian et al., 2020). In addition, the model highlights the significant roles played by health-related fitness and perceived motor competence as mediators between motor competence and physical activity (Stodden et al., 2008). During middle and late childhood, children's perceived motor competence aligns more closely with their actual motor competence (True et al., 2017). Consequently, children who demonstrate higher motor competence tend to feel more confident in their physical abilities and, as a result, show a greater willingness to engage in physical activities (Babic et al., 2014). Conversely, children with lower motor competence may choose not to participate in physical activities because they are aware of their relatively lower competence compared to their peers (Babic et al., 2014). The conceptual model highlights the reciprocal association between motor competence and health-related fitness, which has been observed in multiple reviews (Lubans et al., 2010; Robinson et al., 2015; Cattuzzo et al., 2016; Utesch et al., 2019; Barnett et al., 2022). The suggestion is that children with higher motor competence are more likely to engage in physical activities and, as a result, tend to develop higher levels of health-related fitness (Stodden et al., 2008; Barnett et al., 2022). In their systematic review, Barnett et al. (2022) found strong positive evidence supporting the link between motor competence and health-related fitness. Additionally, Robinson et al. (2015) demonstrated that the association between health-related fitness and motor competence becomes stronger as children transition into adolescence. The conceptual model suggests that improved health-related fitness would, in turn, allow children to engage in physical activity for longer periods, leading to more opportunities for the continued development of motor competence (Stodden et al., 2008). Furthermore, Barnett et al. (2022) found strong positive evidence supporting the fitness-mediated pathway between motor competence and physical activity in both directions.

The underlying idea of the conceptual model is that higher motor competence can lead to either a positive cycle of engagement in physical activity or a negative cycle of disengagement (Stodden et al., 2008). During middle and late childhood, children with lower motor competence may develop lower perceived motor competence, which can lead to a lack of confidence and reluctance to engage in physical activities. This limited participation in physical activity would hinder their development of fitness and provide fewer opportunities for them to further develop their motor competence. The model suggests that children caught in a negative spiral would be more prone to develop an unhealthy weight status. This, in turn, would further negatively impact their motor competence, perceived motor competence, health-related fitness, and physical activity (Stodden et al., 2008). Conversely, children with higher motor competence would not only possess the confidence to engage in physical activity, but they would also improve their fitness levels by being physically active (Stodden et al., 2008). This positive spiral of engagement would then increase their chances of developing a healthy weight status (Stodden et al., 2008). Both Robinson et al. (2015) and Barnett et al. (2022) found a bidirectional relationship between weight status and motor competence. It is noteworthy that weight status may serve as both a precursor and a consequence of motor competence, as highlighted in the findings of Robinson et al. (2015).

Since the conceptual model introduced by Stodden et al. (2008) serves as the framework for this dissertation, the following section thoroughly examines the most reliable empirical evidence on the relationships proposed in the model.

2.7 Empirical evidence for the associations between variables presented in the conceptual model of Stodden et al. (2008)

TABLE 1 Associations between variables presented in the conceptual model of Stodden et al. (2008).

Motor competence	←→	Physical activity Health-related fitness Perceived motor competence Weight status
Physical activity	←→	Health-related fitness Perceived motor competence Weight status
Weight status	←→	Health-related fitness Perceived motor competence

2.7.1 Associations between motor competence physical activity, health-related fitness, perceived motor competence and weight status

Motor Competence and Physical Activity. Stodden et al. (2008) proposed that physical activity plays a crucial role in early childhood by promoting motor competence through various developmental opportunities. Additionally, the authors suggested that in later childhood the relationship reverses, with motor competence driving physical activity by enabling participation in a variety of activities (Stodden et al., 2008). While there is a clear association between motor competence and physical activity throughout childhood and adolescence (Stodden et al., 2008; Lubans et al., 2010; Robinson et al., 2015; Burton et al., 2023), a recent systematic review (Barnett et al., 2022) indicates that the causal relationship has not yet been empirically established. In their systematic review, Barnett et al. (2022) found no evidence supporting the pathway from physical activity to motor competence, while the evidence for the reverse pathway was inconclusive. They suggested that the discrepancy between the conceptual hypothesis (Stodden et al., 2008; Robinson et al., 2015) and their gathered empirical findings may be attributed to bias. Researchers tend to emphasize positive associations and may not fully discuss null or negative associations. Additionally, noting that previous evidence supporting this pathway primarily relied on cross-sectional studies, Barnett et al. (2022) restricted their analysis to longitudinal studies only. However, they conceded that their systematic review did not discriminate between age groups, which could be an important variable for understanding the direction of the pathway. Nilsen et al. (2020) found that higher levels of accelerometer-measured MVPA at baseline (4.7 years) predicted greater motor competence two years later. However, they found no evidence for the reverse pathway. Conversely, V. P. Lopes et al. (2011) and L. Lopes et al. (2019) found evidence for the reverse pathway during adolescence. In 2011, V. P. Lopes et al. found a general trend towards decreased physical activity between ages 6 and 10. However, this trend was less pronounced in children who had a higher initial level of motor competence compared to peers with lower motor competence. Moreover, in 2019, L. Lopes et al. reported longitudinal associations between locomotor skills at baseline (13.49 years) and accelerometer-measured MVPA two years later. The quality of physical activity plays a crucial role in promoting the development of motor skills (Myer et al., 2015). This may partly explain the limited evidence on the longitudinal relationship between physical activity and motor competence. Many studies have focused on measuring the intensity and amount of physical activity without considering the possible impact of motor skill development in different specific activities (Myer et al., 2015).

Contradictory findings on the impact of different motor competence domains on physical activity have been reported. For example, Blomqvist et al. (2019) demonstrated that children with improved locomotor skills showed higher levels of vigorous physical activity at age 11. Similarly, Barnett et al. (2009) emphasized that proficiency in object control at around age 10 predicted self-reported vigorous physical activity during adolescence. Importantly, the assessment methods used in these studies differed. Blomqvist et al. (2019) employed product-oriented measurements, whereas Barnett et al. (2009) used process-oriented measurements. This difference makes direct comparisons challenging. However, both studies highlighted the association between motor competence and vigorous-intensity physical activity. Furthermore, the literature suggests potential gender-related nuances (Logan et al., 2015). Locomotor skills may have a greater impact on girls' physical activity (Slykerman et al., 2016), whereas object-control skills may be more important for boys (Logan et al., 2015), possibly due to gender differences in sports participation (Chalabaev et al., 2013). Experimental studies measuring physical activity following a motor competence intervention or vice versa are few (Engel et al., 2018; Barnett et al., 2022). The limited evidence available indicates that training preschool children in motor competence at least three times a week can increase the intensity of physical activity and reduce sedentary behavior (Engel et al., 2018). Other studies have shown that interventions focusing on physical activity (and motor competence) can enhance motor competence in preschool children (Cohen et al., 2015; Hassan et al., 2022; Huhtiniemi et al., 2023). However, the recent review by Barnett et al. (2022) found insufficient evidence to support the promotion of physical activity through motor competence interventions or the reverse. In summary, the longitudinal association between motor competence and physical activity remains inconclusive (Barnett et al., 2022), highlighting the urgent need for further research to bring clarity to this crucial aspect of child development.

Motor Competence and Health-Related Fitness. The conceptual model (Stodden et al., 2008) proposes that in late childhood a reciprocal relationship exists between motor competence and health-related fitness. It also proposes that health-related fitness is a mediator between motor competence and physical activity. Multiple reviews, including Lubans et al. (2010), Robinson et al. (2015), Cattuzzo et al. (2016), Utesch et al. (2019), and Barnett et al. (2022), have reported positive associations between motor competence and health-related fitness. Utesch et al. (2019) conducted a meta-analysis to investigate the correlation between motor competence and various components of health-related fitness throughout different stages of development, spanning from early childhood to early adulthood. The meta-analysis revealed a positive association between motor competence and health-related fitness, with effect sizes ranging from moderate to large. Moreover, the association between motor competence and health-related fitness was found to strengthen with age (Utesch et al., 2019). Learning a diverse range of motor skills and being able to apply them to more advanced movements can enhance health-related fitness (Barnett et al., 2008; Barnett et al., 2022). For example, a recent study by Sacko et al. (2021) demonstrated that improved movement quality is linked to increased energy expenditure. This suggests that enhanced motor competence may have the potential to improve cardiorespiratory fitness. However, higher levels of health-related fitness can also improve motor competence by allowing individuals to participate in physical activities for longer periods (Henrique et al., 2016). This, in turn, can provide more opportunities for acquiring motor skills.

The evidence strongly supports a positive pathway from motor competence to health-related fitness but remains inconclusive on the reverse relationship (Barnett et al., 2022). However, the relationship between health-related fitness and locomotor skills has been shown to be strong in both directions (Barnett et al., 2022). However, it is important to note that although motor competence and health-related fitness are theoretically distinct constructs, they are inseparable (Utesch et al., 2019). In order to achieve efficient coordinated movements, many motor and fitness tasks require a high level of neuromuscular control, including motor unit recruitment and optimal co-activation of antagonist/agonist muscles (Enoka, 2015; Magill & Anderson, 2017). Moreover, the performance of any movement task necessitates a varying degree of cardiovascular fitness, muscular fitness, and flexibility (Goodway et al., 2021). Thus, there may be some overlap in the content assessed by both motor competence and fitness measures (Utesch et al., 2019). Such overlap may partly explain the strong association observed between fitness and motor competence, especially in locomotor skills. The 20-meter shuttle run test, for example, is widely used to assess cardiorespiratory fitness. However, it is also a measure of locomotor skill as it involves running and changing direction at an accelerating speed (Léger & Lambert, 1982; Masci et al., 2013). The observed association between motor competence and health-related fitness most likely arises from both direct factors, such as similarities in neuromuscular demands (Magill & Anderson, 2017; Goodway et al., 2021), and indirect factors, such as enabling participation in a variety of sustained activities related to practice, gameplay, and performance (Ré et al., 2016; Henrique et al., 2016). For example, Cohen et al. (2015) demonstrated that motor competence in elementary school children mediated the impact of a physical activity intervention on cardiorespiratory fitness (Cohen et al., 2015). Examining the developmental associations between motor competence and health-related fitness in adolescents over extended periods could provide valuable insights into the temporal dynamics of these relationships and enhance our understanding of how these constructs influence each other as children grow and develop. In addition, the design and implementation of intervention studies could further elucidate the potential causal relationships.

Motor Competence and Perceived Motor Competence. The conceptual model by Stodden et al. (2008) posits perceived motor competence as a mediator between motor competence and physical activity. Furthermore, it suggests that the strength of the association between actual and perceived motor competence strengthens across developmental age and is bidirectional in middle and late childhood. A recent meta-analysis (De Meester et al., 2020) showed that the strength of the association between actual motor competence and perceived motor competence/physical self-perception in youth ranged from low to moderate. In early childhood, children often tend to overestimate their competence by confusing their desire to be competent with the reality of their situation (Harter, 1999). According to the conceptual model proposed by Stodden et al. (2008), such overestimation may initially encourage children to engage in physical activities, thereby promoting the acquisition of motor skills in early childhood. According to Harter (1982), until they around 8 years of age, children have a limited capacity to accurately perceive their own competence. As children grow older and undergo cognitive development, they become more capable of evaluating their own skills and comparing them with those of their peers (Harter, 1999). Thus, children's perceptions of their motor competence become increasingly accurate, as demonstrated in an empirical study by True et al. (2017). Perceptions of one's own skills may occur through comparison with an internal standard, such as previous behavior, or through a relational definition, i.e., in relation to others (Harter, 1978). How well children's perceived motor competences align with their actual motor competences may vary depending on how these constructs are identified or measured, such as perceived motor competence or perceived confidence (Estevan & Barnett, 2018). Person-oriented studies, which consider intra-individual differences, have identified children and adolescents who overestimate, underestimate, and accurately estimate their motor competence (De Meester et al., 2016; Utesch et al., 2018; Niemistö et al., 2023; Almeida et al., 2023). Furthermore, this alignment may have an impact on their physical activity behavior (De Meester et al., 2016; Utesch et al., 2018), as discussed in Chapter 2.7.2.

Motor Competence and Weight Status. In the conceptual model of Stodden et al. (2008), weight status is an outcome measure. However, the authors also note that weight status further impacts the other variables included in the model (Stodden et al., 2008). There is strong evidence of a negative association between motor competence and weight status (Robinson et al., 2015; Barnett et al., 2016; Barnett et al., 2022; Martins et al., 2023), which appears to be more pronounced in individuals with higher BMI (Martins et al., 2023). Furthermore, a recent systematic review of longitudinal studies confirmed that this association is bidirectional (Barnett et al., 2022). Moreover, an association with weight status has been found for all the domains of motor competence, including locomotor skills (Lima et al., 2021), object control skills (Slotte et al., 2017), and balance skills (Haapala et al., 2016). These findings are supported by both product- and process-oriented measurements (Slotte et al., 2017; Lima et al., 2021; Martins et al., 2023). Hence, the accumulation of excess fat mass can hinder the development of motor competencies (Chivers et al., 2013; Barros et al., 2021) by reducing movement efficiency and limiting the ability to perform specific motor skills (Nantel et al., 2011; Haapala et al., 2016). Moreover, children with fewer improvements in motor competence may have had fewer opportunities to engage in a variety of physical activities that could have further moderated their weight development (V. P. Lopes et al., 2012; Rodrigues et al., 2016). However, the strong association between motor competence and weight status may partially be explained by the weight-bearing nature of many motor skill assessments (Webster et al., 2021). Poor performance scores, especially in locomotor tasks such as jumping and leaping, may be influenced less by motor coordination and more by the morphological constraints posed by overweight and obesity when seeking to move the body through space, particularly against the force of gravity (Chivers et al., 2013; Webster et al., 2021). This notion has been supported by previous studies showing that weight loss is associated with improved motor skills in children (Chivers et al., 2013; Lima et al., 2021). For example, Lima et al. (2021) reported that children who transitioned from being overweight to having a normal weight status over a period of two to four years showed locomotor competence similar to that of children who consistently maintained a normal weight. However, Rodrigues et al. (2016) found a reverse relationship, in which the development of motor competence influenced the likelihood of later overweight. They found that children with a lower rate of change in motor (locomotor) competence were at increased risk for overweight and obese status compared to peers with a higher rate of change, irrespective of BMI at baseline (Rodrigues et al., 2016). Similarly, V. P. Lopes et al. (2012) found that higher baseline locomotor competence was associated with a smaller increase in skinfold thickness from 6 to 10 years of age. Thus, the evidence suggests that motor competence may be both a precursor and a consequence of weight status (Robinson et al., 2015). Poor motor competence can contribute to unhealthy weight development by limiting physical activity (Rodrigues et al., 2016), whereas excess weight can impede the development of motor skills (Chivers et al., 2013; Lima et al., 2021). However, to better understand the complex relationship between motor competence and weight status that emerges early in childhood, robust longitudinal and experimental designs are required (Martins et al., 2023).

2.7.2 Associations between physical activity and health-related fitness, perceived motor competence and weight status

Physical Activity and Health-Related Fitness. In the conceptual model of Stodden et al. (2008), the relationship between health-related fitness and physical activity is reciprocal. The primary factor that can be modified to enhance health-related fitness is physical activity (Raghuveer et al., 2020). On the other hand, higher fitness levels may enable continued participation in physical activities (Ré et al., 2016) and promote a greater ability to be physically active (Stodden et al., 2008). Regular engagement in physical activity, especially in vigorous physical activity, induces physiological adaptations in the cardiorespiratory (Raghuveer et al., 2020) and neuromuscular systems (Folland & Williams, 2007). However, the response of health-related fitness to physical activity varies, even among sedentary individuals (Bouchard & Rankinen, 2001). This observed heterogeneity is not random but tends to cluster within families due to a combination of genetic and environmental influences (Bouchard & Rankinen, 2001). Neither cardiorespiratory nor muscular fitness is a static trait; instead, they can change and tend to decline when physical activity is reduced in intensity, duration, or frequency (McArdle, 2015; Spiering et al., 2021). Thus, cardiorespiratory and muscular fitness can serve as indicators of an individual's previous engagement in intensive physical activity (Ruiz et al., 2006; Smith et al., 2019). Youth participation in organized sports is significantly associated with health-related fitness (Kokko et al., 2019). This association is attributed to the regularity, structure, and vigorous intensity inherent in such a context (Machado-Rodrigues et al., 2012; Toivo et al., 2023). Research has consistently demonstrated that children engaged in organized sports tend to accumulate higher levels of physical activity (Kokko et al., 2019) and exhibit higher levels of cardiorespiratory fitness (Telford, Telford, Cochrane et al., 2016) and muscular fitness (Smith et al., 2019) than peers who do not participate in such activities. However, children with lower cardiorespiratory fitness appear to be more likely to drop out of organized sports (Moa et al., 2020). Hence, the association between organized sport participation and health-related fitness may be bidirectional. The conceptual model (Stodden et al., 2008) suggests a virtuous cycle, in which a higher level of health-related fitness promotes an active lifestyle (Moa et al., 2020). Additionally, engaging in regular physical activity further improves health-related fitness (Ortega et al., 2008; Armstrong et al., 2011; Raghuveer et al., 2020). In summary, maintaining a physically active lifestyle is crucial for both improving and maintaining cardiorespiratory and muscular fitness. However, in order to fully understand and address the potential reciprocal influences and dynamics, additional longitudinal research is needed. This research should, for example, focus on clarifying strategies to overcome the potential obstacle that low fitness levels may pose to active participation in physical activities, including organized sports.

Physical Activity and Perceived Motor Competence. Research has demonstrated a strong positive association between perceived physical competence and engagement in physical activity (Babic et al., 2014). The conceptual model of Stodden et al. (2008) posits a reciprocal association between physical activity and perceived motor competence, suggesting that perceived motor competence acts as a mediator between motor competence and physical activity. The meta-analysis conducted by Babic et al. (2014) emphasized the potential bidirectional relationship between perceived physical competence and physical activity. While engaging in physical activities may lead to improvements in perceived motor competence (Stodden et al., 2008), individuals who already have high levels of physical self-concept may be naturally more inclined to participate in physical activities (Babic et al., 2014). Morrison et al. (2018) found that perceived athletic competence accounted for approximately 17% of the total variance in self-reported physical activity participation. On the other hand, factors such as BMI, motor competence, and socioeconomic status explained less than 1% of the variance. Similarly, Bardid et al. (2016) demonstrated that children aged 9 with lower levels of perceived motor competence had significantly lower autonomous motivation towards sports than peers with higher perceived motor competence, irrespective of their actual motor competence levels. These findings suggest that a high perceived competence, or even an overestimation of one's motor competence, could have a positive impact on motivation for physical activity, as also suggested by De Meester et al. (2016). However, Utesch et al. (2019) found in contrast that both overestimating and underestimating one's own motor competence at age 9 led to a lower level of self-reported physical activity one year later. They suggested that children who overestimate their competence may face failures, as they lack the necessary skills to complete physical tasks, while those who underestimate their competence may be hesitant to attempt new tasks (Utesch et al., 2019). The field would benefit from longitudinal research that examines the developmental associations between perceived motor competence and physical activity.

Physical Activity and Weight Status. Physical activity plays an important role in preventing childhood and adolescent overweight and obesity (Katzmarzyk et al., 2015; Sprengeler et al., 2021; Mahumud et al., 2021). By participating in physical activity, adolescents can increase their daily energy expenditure, which in turn contributes to maintaining a healthy energy balance (Westerterp, 2017). Physical activity also has the potential to suppress appetite, which can further contribute to weight management (Fedewa et al., 2018). There is strong observational evidence that an association exists between a lower prevalence of obesity and higher levels of physical activity in children (Jiménez-Pavón et al., 2010; Mahumud et al., 2021). Moreover, a meta-analysis conducted by Stoner and colleagues in 2016 demonstrated the effectiveness of exercise interventions in reducing body fat percentage among adolescents with overweight and obesity. While observational evidence consistently demonstrates an association between higher levels of physical activity and a lower body mass index (Jiménez-Pavón et al., 2010), it has been argued that lack of physical activity is not the primary driver of overweight and obesity (Malhotra et al., 2015). The relationship between physical activity and weight status is more complex and bidirectional in nature (Sprengeler et al., 2021). Sprengeler et al. (2021) showed that although engaging in sufficient MVPA prevented overweight in later childhood, it was challenging for children who were already overweight to reach such high levels of MVPA. Children with overweight or obesity may experience limitations in their physical functioning, including motor competence (Webster et al., 2021) and health-related fitness (Moliner-Urdiales et al., 2011). The limitations in physical functioning related to weight, along with the heightened risk of negative social experiences (Zabinski et al., 2003), can lead to decreased levels of physical activity. This can potentially worsen weight gain and perpetuate a harmful cycle, as proposed in the conceptual model by Stodden et al. (2008). Taken together, the intricate relationship between physical activity and weight status in childhood highlights the necessity for comprehensive longitudinal studies that integrate objective measurements, as emphasized in recent research (Sprengeler et al., 2021).

2.7.3 Associations between Weight Status and Health-Related Fitness and perceived motor competence

Weight status and health-related fitness. Children with overweight or obesity generally have lower cardiorespiratory (Pate et al., 2006; Moliner-Urdinales et al., 2011; Rauner et al., 2013) and muscular fitness (Thivel et al., 2016) compared to children with normal weight. However, it is important to understand that excess weight does not necessarily affect absolute oxygen uptake (Goran et al., 2000) or muscular strength (Thivel et al., 2016); instead, it increases the workload and inertia of the body. For example, while excess body fat does not necessarily reduce the ability to consume oxygen maximally (VO2max), it has a detrimental effect on submaximal aerobic capacity (Goran et al., 2000). Given that fat mass is metabolically inactive, it primarily increases workload without corresponding improvements in oxygen metabolism (McArdle, 2015). Consequently, tests such as the 20-meter shuttle run, or the push-up test often result in lower performance and overall scores for individuals with excess fat. In the scientific literature, this is often referred to as poor health-related fitness (Welsman & Armstrong, 2019; Thivel et al., 2016; Tomkinson et al., 2019). However, it is important to consider that maximal oxygen uptake is usually scaled according to the individual's body weight (mL/kg/min) or fat-free mass (Raghuveer et al., 2020), which is then correlated with submaximal measurements (Ramsbottom et al., 1988). These considerations extend to muscular fitness. In laboratory-based studies, adolescents with obesity might initially exhibit higher levels of absolute muscular fitness compared to their lean counterparts. However, when adjusted for factors such as body weight and lean mass, these differences become negligible, which is consistent with findings from field-based investigations (Thivel et al., 2016). In the everyday lives of children, tests that measure cardiorespiratory fitness, such as the 20-meter shuttle run, and muscular fitness, like the push-up test, are significant indicators. They reflect the ability to engage in sports, games, recreational activities, and perform everyday tasks with greater ease and efficiency (Tomkinson et al., 2019). Importantly, being overweight (Ekelund et al., 2017) and having poor fitness (Moa et al., 2020) may precede low levels of physical activity, which in turn can contribute to a self-perpetuating cycle (Janssen & LeBlanc, 2010). Empirical evidence has shown that both the initial level and the progression of cardiorespiratory fitness are associated with changes in weight status (Rodrigues et al., 2016; Byrd-Williams et al., 2008). Rodrigues et al. (2016) found that children with the slowest rate of change in cardiorespiratory fitness had the highest odds of developing overweight or obesity. Similarly, Byrd-Williams et al. (2008) demonstrated that in boys, higher baseline cardiorespiratory fitness was inversely associated with the rate of increase in adiposity. However, Perez-Bey et al. (2020) demonstrated that alterations in body fatness were linked to subsequent levels of cardiorespiratory fitness, irrespective of initial cardiorespiratory fitness levels. In conclusion, the evidence suggests a bidirectional relationship between cardiorespiratory fitness and weight status in children and adolescents. Therefore, conducting comprehensive longitudinal studies that examine the relationship between changes in health-related fitness and changes in weight status could be advantageous.

Weight Status and Perceived Motor Competence. Children who are overweight or obese often face increased levels of stigmatization (Brewis, 2014) and are more likely to be bullied and intimidated in sports settings compared to their thinner peers (Sweeting & West, 2001). These experiences can have a significant impact on their perceived motor and sport competence, as these perceptions are heavily influenced by their social environment (Estevan & Barnett, 2018). Previous empirical studies (Jones et al., 2010; Southall et al., 2004) have consistently found that children with overweight and obesity tend to report lower levels of perceived motor competence and physical activity self-efficacy compared to their non-overweight counterparts. For example, Southall et al. (2004) identified significant differences in perceived locomotor skills, but not in perceived object control skills, a finding which mirrors the distinctions observed in actual motor competence between children with normal weight and overweight (Webster et al., 2021). Furthermore, parents of children with overweight often perceive their children as being less skilled in sports than their leaner peers (Jones et al., 2010). This parental perception has been shown to negatively impact children's perception of their own physical competence (Bois et al., 2005). Adding to this complexity, Utesch et al. (2018) reported that both overestimating and underestimating one's own motor competence can lead to reduced levels of future physical activity. This effect is particularly pronounced among children who are underweight, overweight, or obese. Consequently, solely promoting self-perceptions to encourage higher levels of physical activity may not be advisable for children who are underweight or overweight (as suggested by De Meester et al., 2016). However, evidence on the possible developmental association between perceived motor competence and weight status remains scarce. This underscores the need for longitudinal studies to explore this relationship and gain a more comprehensive understanding of the interplay between psychological and physical aspects of child development.

2.8 The rationale of the current study

Although the conceptual model proposed by Stodden et al. (2008) is well-known, widely cited, and extensively studied, longitudinal studies that have simultaneously examined multiple variables and time points are lacking (Barnett et al., 2022). Moreover, the evidence for many of the hypothesized pathways remains inconclusive. A small number of studies focusing on adolescent populations exist, largely because the conceptual model of Stodden et al. (2008) primarily focuses on early, middle, and late childhood. Moreover, adolescence is recognized as an important developmental period as many NCDs that manifest in adulthood can be partially attributed to modifiable risk behaviors, such as physical activity, that are established during this time (van Sluijs et al., 2021). Thus, there is a need to expand the conceptual model to include adolescence and investigate the proposed developmental associations during this crucial period.

Typically, based on the assumption that individuals are homogeneous, empirical studies have favored a variable-oriented analytical approach (von Eye & Bogat, 2006). However, adolescents have been shown to demonstrate significant heterogeneity in the development of motor competence (Coppens et al., 2019), health-related fitness (Raghuveer et al., 2020), perceived competence (Almeida et al., 2023), physical activity (Lounassalo et al., 2019), and weight status (Oluwagbemigun et al., 2019). In variable-centered studies, where the focus is on analyzing relationships between variables across a group, the emphasis is on revealing general patterns and associations based on mean values (von Eye & Bogat, 2006). While valuable for assessing overall trends, these studies may not account for individual differences within groups, potentially overlooking important variations among individuals (von Eye & Bogat, 2006). To overcome this limitation and gain a more comprehensive understanding, it is important to consider person-centered approaches when applying the Stodden et al. (2008) model as a research framework. These methods identify subgroups or clusters of individuals with similar characteristics or trajectories, thereby acknowledging and exploring the diversity in development within the larger population (von Eye & Bogat, 2006). This dissertation research aimed to address the aforementioned gaps in the existing literature by employing person-oriented analytical approaches to the study of a substantial longitudinal dataset that captures annual data from an adolescent population.

While prior research, such as the study conducted by Rodrigues et al. (2016), has investigated the longitudinal associations between the variables described in the Stodden et al. (2008) model, no study has thoroughly examined these variables simultaneously across multiple time points from early to middle adolescence. This is important because, as pointed out in the introduction, all the relevant variables have been shown to be associated with each other. For example, Rodrigues et al. (2016) included only motor competence, cardiorespiratory fitness, and weight status. They showed that less improvement in cardiorespiratory fitness and motor competence increased the risk of becoming overweight or obese during childhood. To enhance our understanding of the developmental relationships among all five variables during adolescence, they were examined concurrently over four time-points (Study I).

Previous studies have shown significant variation in the development of the variables presented in the model by Stodden et al. (2008). For example, Coppens et al. (2019) found inter-individual variation in the development of motor competence, whereas Rodrigues et al. (2016) revealed intra-individual variation in the development of BMI and health-related fitness. Person-oriented statistical methods allow for the consideration of intra- and inter-individual variation. Some previous studies (Jaakkola et al., 2020; 2021; Estevan et al., 2021) have profiled children based on the variables presented in the model of Stodden et al. (2008). However, none of the previous studies have included all the variables or examined the stability of these profiles throughout adolescence. Therefore, to address this research gap, latent transition analysis was employed to identify profiles based on all the variables outlined in the model by Stodden et al. (2008) and to examine the stability of these profiles over time (Study II).

The existence of a motor proficiency barrier was listed as one of the top 10 research questions by Malina (2014). The concept of the motor skill proficiency barrier was initially introduced in 1980 by Seefeldt and later expanded upon by Haubenstricker and Seefeldt (1986). Individuals below this hypothesized barrier would find it more difficult to learn advanced skills and therefore have less success in participating in physical activities. Furthermore, the conceptual model proposed by Stodden et al. (2008) indicates that during late childhood, having sufficient motor competence plays a pivotal role in promoting physical activity. Nevertheless, the existence of this pathway was not supported in a recent systematic review (Barnett et al., 2022), highlighting the importance of conducting longitudinal studies with multiple time points. Prior longitudinal studies have documented less favorable improvements in cardiorespiratory fitness (Rodrigues et al., 2016; Hands, 2008; Fransen et al., 2014; Haugen & Johansen, 2018) and physical activity (V. P. Lopes et al., 2011; V. P. Lopes et al., 2021) among individuals with low motor competence. However, these studies assessed physical activity using questionnaires alone (V. P. Lopes et al., 2011; V. P. Lopes et al., 2021), and none of them simultaneously investigated trajectories of both cardiorespiratory fitness and physical activity. Therefore, we used latent profile analysis to identify profiles of adolescents based on their motor competence levels over time. We then examined the trajectories of physical activity and cardiorespiratory fitness in each of the identified motor competence profiles (Study III).

Although motor competence is considered a key factor influencing physical activity behavior, health-related fitness, and weight status in the conceptual model of Stodden et al. (2008), it is important to recognize that there are other contextual factors that also impact these variables. While health-related fitness itself is crucial for adolescents' health (Lang et al., 2018; de Lima et al., 2022), it can also serve as an indicator of previous physical activity. Children exhibit different levels of cardiorespiratory fitness, muscular fitness, and weight status during adolescence. One factor that plays an important role in promoting physical activity and fitness in youth is participation in organized sports (Kokko et al., 2019). As many children drop out of organized sports during adolescence (Crane & Temple, 2015; Kokko et al., 2019), it is important to note that there is currently no evidence on the impact of dropping out of organized sports on the development of BMI, cardiorespiratory fitness, and muscular fitness in adolescents. Therefore, multi-group latent growth modeling was employed to analyze the trajectories of health-related fitness and BMI among three groups: those who dropped out of organized sports during adolescence, those who never participated or dropped out before adolescence, and those who continued participation throughout adolescence (Study IV).

3 DISSERTATION PURPOSE AND AIMS

The primary objective of this dissertation research was to investigate the longitudinal relationships from early to middle adolescence between five variables: motor competence, perceived motor competence, health-related fitness, physical activity, and BMI. The approach taken was based on the conceptual model proposed by Stodden et al. in 2008. Covariates such as maturation, gender, and participation in organized sports were considered as integral aspects of developmental differences. The overall aim was to provide insights into the dynamic development of factors that promote a physically active lifestyle among adolescents. The specific objectives of the four original studies were as follows:

I. To study developmental associations between motor competence, perceived motor competence, cardiorespiratory fitness, MVPA, and BMI from early to middle adolescence.

II. To identify profiles of adolescents based on their motor competence, perceived motor competence, cardiorespiratory fitness, MVPA, and weight status, and to examine the stability of the profile memberships from early to middle adolescence.

III. To identify profiles of adolescents based on their motor competence and, based on these motor competence profiles, to examine their trajectories of cardiorespiratory fitness and MVPA from early to middle adolescence,

IV. To examine differences in the development of health-related fitness and BMI among three groups of sport participants: 1) those who continued or started participation in organized sport, 2) those who dropped out of sport, and 3) those who never participated in sport or dropped out before adolescence.

4 MATERIALS AND METHODS

4.1 Study design and participants

A four-year longitudinal follow-up dataset was utilized in this dissertation research. The first data collection phase was conducted between August and October 2017. Thereafter, data were collected annually during the same months from 2018 to 2021. Studies I and II were based on the data gathered during first four time points, i.e., 2017-2020. Study III was based on data from all five time points and Study IV on data from 2017, 2019, and 2021. The timeline and timepoints used in each study are presented in Figure 3. Participants were recruited from 65 elementary schools in four cities across four of five Finland's regions, namely South, North, Central, and East Finland. In each school, all 5th grade students (aged between 11 and 12 years) were invited to participate. Of these, 1 167 children took part in the study (girls = 583, boys = 565; Mage = 11.27 ±0.33). The participants accounted for 2% of the same-age Finnish population (Statistics of Finland, 2017). All assessments were conducted by trained researchers during school hours. Questionnaires (perceived motor competence and sport participation) were administered in a classroom setting, while motor competence and fitness assessments were carried out in an indoor gymnasium setting. Anthropometric measures were assessed individually in a private area. Accelerometers were distributed and collected during school hours.

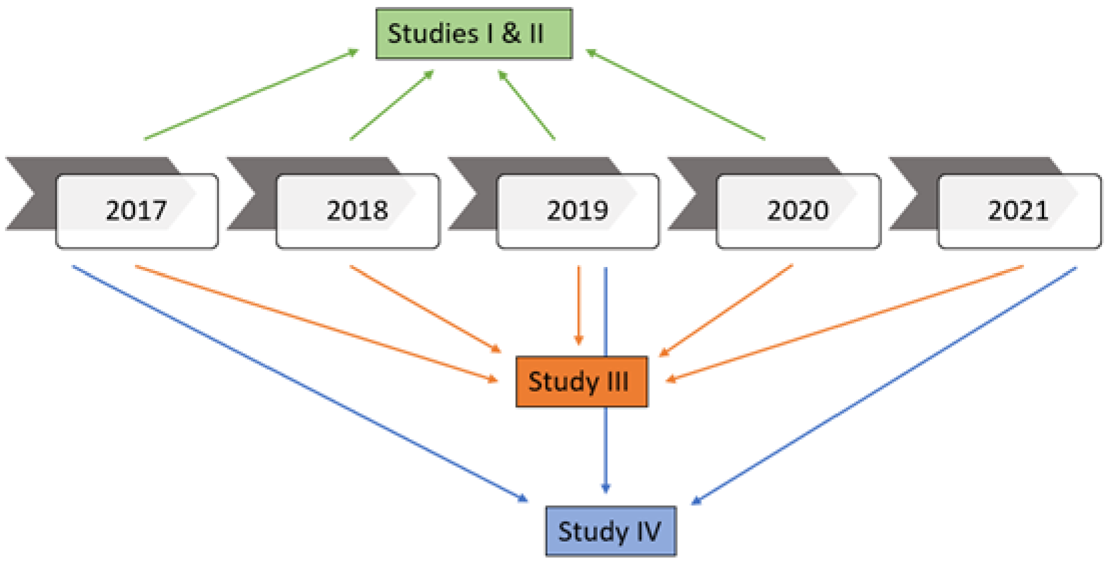


FIGURE 3 Timeline of data collection and time points used in Studies I, II, III and IV.

4.2 Study ethics

Throughout the entire research process, from participant recruitment to data analysis and reporting, the researcher and research assistants consistently adhered to the principles of good scientific conduct. All the studies comprising this dissertation were conducted following the guidelines of the Declaration of Helsinki (World Medical Association, 2013). Since the research participants were adolescents, special emphasis was placed on adhering to ethical protocols and the principles outlined in the United Nations (1989) Convention on the Rights of the Child. Prior to commencing the research, the University of Jyväskylä ethics committee approved the study protocols. Participants and their legal guardians were provided with comprehensive explanations of the research objectives and methods, and of participants' rights prior to entering the study. Furthermore, written consents from the participants' legal guardians were obtained and the participants confirmed their willingness to participate before the data collection commenced. Participation in the research was entirely voluntary, and participants had the right to withdraw at any point without any repercussions or consequences. It should be noted that the participants received written feedback on their individual results every year.

4.3 Assessments

4.3.1 Motor competence

The motor competence measurements consisted of object-control skills and locomotor skills. *Object-control skills* were measured using a throw-catch combination test (Jaakkola et al., 2012). In this test, participants were given instructions to throw a tennis ball from behind a designated line. The throwing distance for 5th and 6th grade girls was 7 meters and for boys 8 meters. For girls in 7th to 9th grade, the distance was 8 meters, and for boys 10 meters. Participants were instructed to aim their throw at a square measuring 90cm x 90cm, which was taped or painted on the wall at a height of 90cm above floor level. After throwing the ball, participants were to attempt to catch it after a single bounce. Thus, a successful combination required hitting the designated square and successfully catching the ball after just one bounce. No time limit was imposed. The protocol was repeated 20 times, and the result was the sum of successful throw-catch combinations. *Locomotor skills* were assessed using four different tests: the 5-leap test and three subtests from Körperkoordinationstest für Kinder (KTK). Lateral jump, moving sideways, and walking backwards on a beam are components of the KTK measurement battery (Kiphard & Schilling, 2007). It should be recognized that the KTK test battery is a measure of students' gross motor coordination. In the 5-leap test, participants start with their feet together and then jump forward using their preferred leg. They repeat this sequence for five consecutive leaps and, after the final leap, land with their feet together. The result was measured as the distance covered in meters, with a margin of 10 centimeters. Participants were given the opportunity to perform the test twice, and the higher of the two scores was recorded as the result. The lateral jump test was conducted on a small mat with a wooden slat positioned in the center. Participants were instructed to jump from side to side over a 2-cm high wooden slat as quickly as possible for a period of 15 seconds. The test was conducted twice, and the result was the sum of jumps from both trials. In the moving sideways test, participants were instructed to sequentially move small wooden blocks from left to right while moving sideways on top of them. They started by moving the first block to the right and placing their feet on it. The task was to complete as many of these block movements as possible in a time limit of 20 seconds. The result was the sum of the blocks moved across two trials. The walking backwards on a beam test involved walking backwards on three different balance beams with widths of 6 cm, 4.5 cm, and 3 cm, respectively. After a practice trial, participants were instructed to walk slowly backwards on the 6-cm beam, with the goal of avoiding contact with the ground. A total of nine trials, three for each beam, were performed. The result was the sum of error-free steps taken backwards from all trials. The maximum score for each trial was 8, resulting in a potential total score of 72.

4.3.2 Perceived motor competence

Participants' perceived motor competence was assessed using the Finnish version of the Physical Self-Perception Profile, with a specific emphasis on the sport competence dimension (Fox & Corbin, 1989). The assessment consisted of five items related to sports skills, athletic ability, confidence in movement, participation in sports activities, and willingness to engage in sports. The original questionnaire has been revised. Each item began with the stem "What am I like?" The participants were rated on a 5-point scale, ranging from 1 (e.g., "I'm not among the best when it comes to athletic ability") to 5 (e.g., "I'm among the best when it comes to athletic ability"). A previous study with Finnish children demonstrated acceptable construct validity (comparative-fit index (CFI) = 0.98, Tucker-Lewis index (TLI) = 0.97, root mean square error of approximation (RMSEA) = 0.074) and internal consistency (Cronbach's α = 0.90)) (Gråstén, 2014).

4.3.3 Health-related fitness

The health-related fitness assessments comprised tests for cardiorespiratory fitness and muscular fitness. *Cardiorespiratory fitness* was measured by the 20-meter shuttle run test (Jaakkola et al., 2012; Léger et al., 1988; Léger & Lambert, 1982), also known as PACER (Plowman, 2013). A 20-meter track was marked on the floor with two parallel lines, and the running pace for each 20-meter shuttle was determined by the frequency of recorded beeps. Participants were given instructions to continuously run back and forth on the 20-meter track, in synchrony with the beeps. The initial running velocity was set at 8.5 km/h for the first minute and increased stepwise by 0.5 km/h for each minute thereafter. Participants were instructed to stop the test once they were no longer able to maintain the pace set by the beeps. The result of the test was determined by the number of completed shuttles. *Muscular fitness* was measured using a push-up test (Jaakkola et al., 2012). Prior to the test, participants were given instructions to assume the starting position for the push-ups. For boys, the position required that their toes touched the floor, while for girls the position required that their knees touched the floor. Participants were then instructed to complete as many push-ups as possible within a 60-second time frame. The correct technique involves lowering the body until a 90-degree angle is formed at the elbows, with the upper arms parallel to the floor. Participants were instructed to maintain a straight back and knees while pushing up until their arms were fully extended. The result was the number of successful push-ups completed within the allotted time.

4.3.4 Physical activity

Participants' MVPA was assessed using Actigraph wGT3X+ accelerometers (Pensacola, FL, USA). They were instructed to wear the device on their right hip for seven consecutive days, throughout all waking hours, except during bathing or engaging in water-based activities such as swimming. The accelerometers recorded raw accelerations at a frequency of 30 Hz, which were then converted into counts for 15-second epochs. Data reduction was performed using customized Visual Basic macro software in Excel. For a day to be classified as valid for physical activity monitoring, recorded values for at least 500 minutes per day for at least two weekdays and one weekend day within the general waking hours of 7:00 to 23:00 were required. Periods of 30 minutes with consecutive zero counts were considered as non-wear time, and any values exceeding 20 000 counts per minute were considered as spurious accelerations and discarded (Heil et al., 2012). MVPA was calculated using cut points (Evenson et al., 2008), with a threshold of ≥2,296 counts per minute indicating MVPA. The cut-points for assessing MVPA recommended by Trost et al. (2011), based on findings from their controlled clinical trial, were used.

4.3.5 Weight status

Participants' BMI was determined by calculating the ratio of their weight (in kilograms) to the square of their height (in meters), resulting in a measurement of kilograms per square meter. Body weight was measured using calibrated scales (Point electronic personal scale) to within an accuracy of 0.1 kg. Height was measured using portable measuring equipment, specifically a tape, to within an accuracy of 0.5 cm. For the height and weight measurements, the participants wore lightweight clothing and were barefoot. To determine participants' weight status, extended international BMI cutoff values provided by the IOTF were utilized. These cutoffs, as outlined by Cole and Lobstein (2012), categorize individuals into different weight status categories, including thinness, normal weight, overweight, and obesity.

4.3.6 Organized sport participation

Sport club participation was assessed using a single question "Do you engage in exercise or sports in a sport club?" Participants were provided with four response options: 1) "Yes, regularly and actively," 2) “Yes, every now and then”, 3) "Not anymore, but I used to," and 4) "No, I don't. I never have done." (Mononen et al., 2016).

4.3.7 Maturation

Maturation status was assessed using peak height velocity (PHV). The maturity offset was calculated using an equation that accounts for age and height, following the procedures outlined by Moore et al. (2015). The maturity offset represents the difference in years from when the child reaches PHV. A negative offset indicates that PHV has not yet been reached, while a positive offset exceeding 1.5 signifies that PHV has taken place. A positive value below 1.5 suggests that the child is currently experiencing PHV.

TABLE 2 Summary of variables and their measurements across studies.

Variable	Measurement	Origin of the measurement	Article
Motor competence	Throw-catch combination test	Jaakkola et al. (2012)	I,II,III
	5-leap test	Jaakkola et al. (2012)	I,II,III
	Lateral jump test	Kiphard & Schilling (2007)	III
	Moving sideways test	Kiphard & Schilling (2007)	III
	Walking backwards test	Kiphard & Schilling (2007)	III
Health-related fitness	20-meter shuttle run test	Léger & Lambert (1988)	I,II,III,IV
	Push-up test	Jaakkola et al. (2012)	IV
Perceived motor competence	Perceived sport competence	Fox & Corbin (1989)	I,II
Physical activity	Accelerometer-measured MVPA	Actigraph GT3X+ (Pensacola, FL, USA)	I,II,III
	Sport participation	Mononen et al. (2016)	IV
Weight status	BMI	Cole & Lobstein (2012)	I,II,IV
Maturation status	Peak height velocity	Moore et al. (2015)	III,IV

4.4 Statistical analyses

This section summarizes the statistical methods used in the studies. For more detailed information, see the original studies. Preliminary and basic analyses, including descriptive statistics, correlations, logistic regression, analysis of variance (ANOVA) with post hoc tests, independent sample t-test, the missing completely at random (MCAR) test, and identification of outliers, were performed using SPSS software (IBM SPSS Statistics 28.0.0.0). All subsequent analyses were conducted using MPLUS software version 8.0 (Muthén & Muthén, 2017). Results were considered statistically significant at the $p < .05$ level.

In Study I, latent growth curve modeling was used to analyze the levels and slopes of actual motor competence, perceived motor competence, cardiorespiratory fitness, physical activity, and BMI. In this context, "level" refers to the initial values of the observed variables at the baseline, while "slope" refers to the rate of change in those variables over time (see Figure 4).

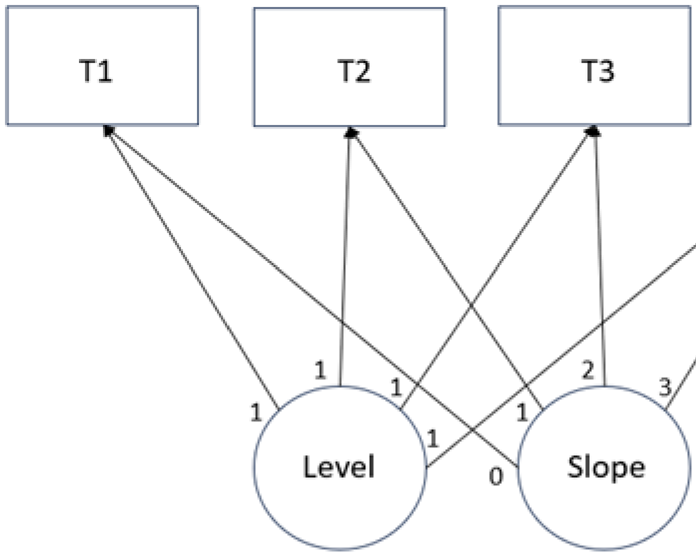


FIGURE 4 Latent growth curve model.

This model allows for the simultaneous examination of the growth trajectories of multiple variables and their interrelationships over time (Duncan & Duncan, 2009). The default models for longitudinal development were constructed by setting the loadings of the latent variables to 1 for the initial level and from 0 to 3 for the slope. Missing values were estimated using the robust full-information maximum likelihood (MLR) estimator. In the analysis, four time points were used to construct five simultaneous latent growth curves for the study variables. In addition, correlations between levels and slopes were estimated to examine the reciprocal relationships within and between variables. Cronbach's α was calculated to assess the internal consistency of the perceived competence scale. Several model fit indices and their criteria were used to examine the goodness-of-fit of the model with the given dataset: model chi-square ($\chi 2$), RMSEA, TLI, CFI, and standardized root mean square residual (SRMR) (Hu & Bentler, 1999). The criteria utilized were based on Hu & Bentler's (1999) recommendations: RMSEA should be close to .06, TLI and CFI should be close to .95, and SRMR should be close to .08.

In Study II, first, latent transition analysis was used to initially identify subgroups of children based on their actual motor competence, perceived motor competence, cardiorespiratory fitness, physical activity, and weight status. Second, the stability of these profiles was examined. To conduct a latent transition analysis, which is a longitudinal extension of latent profile analysis, a five-step model was applied following the procedures outlined by Nylund et al. (2007). The five-step model is presented in Table 3. The robust full-information maximum likelihood (MLR) estimator was implemented to estimate missing values. ANOVA with Tukey's post hoc test was conducted to examine significant differences in the study variables between the profiles.

TABLE 3 Five-step model for transition analyses. Adapted and modified from Nylund et al. (2007).

Step	Procedure
1	Identifying profiles by conducting a cross-sectional latent profile analysis at each time point. The optimal number of profiles was determined using various indices, including Akaike's information criterion (AIC), Bayesian information criterion (BIC), the adjusted BIC (ABIC), entropy, and the adjusted Lo-Mendell-Rubin likelihood ratio test (ALMR-LTR).
2	Structural differences between the profiles at different time points were examined by comparing the measurement invariance model to the measurement variance model. The $\chi 2$ test was conducted using the maximum likelihood estimator with Satorra-Bentler scaling correction to assess the fit of the two models.
3	The most appropriate solution was determined for further analysis. If the models exhibited significant differences, the measurement variance model was selected. In addition, the latent statuses were defined based on the selected model.
4	Transition probability invariance was assessed by constraining the transition probabilities to be equal across different time points. The constrained model was then compared to the freely estimated model using a $\chi 2$ test to determine if there were any significant differences between the two models.
5	"Sex" was added to the selected model as a covariate.

In Study III, auxiliary regression analysis was employed to identify subgroups of children based on their motor competence z-scores from all five time points. Subsequently, simultaneous latent growth curves were derived for each of these subgroups to analyze the initial levels and slopes of MVPA and cardiorespiratory fitness. The study also examined the correlations between the slopes of MVPA and cardiorespiratory fitness. An auxiliary regression model was conducted in two steps, as presented in Table 4 (Asparouhov & Muthén, 2021). The MLR estimation method was implemented to estimate missing values. Both steps were estimated using the TYPE=COMPLEX approach (Muthén & Muthén, 2017) in Mplus, which corrects standard error distortions caused by the clustering of students in school classes. Moreover, logistic regression coefficients were used to estimate the odds ratios of the motor competence profiles for achieving MVPA guidelines. ANOVA with Tukey's post hoc analysis was conducted to identify any statistical differences in the mean levels of variables between the motor competence profiles.

TABLE 4 Two-step model for auxiliary regression model. Adapted and modified from Asparouhov & Muthén (2021).

Step	Procedure
1	Identifying profiles by conducting a longitudinal latent profile analysis for all motor competence measurement z-scores across five time points simultaneously. The optimal number of profiles was selected based on various indices, including AIC, BIC, ABIC, and ALMR-LTR.
2	Estimating latent growth curve models for MVPA and cardiorespiratory fitness over five time points for each motor competence profile.

In Study IV, multi-group latent growth curve modeling was used to estimate the initial levels and slopes of cardiorespiratory and muscular fitness in the different sport participation groups. First, sport participation groups were formed based on the answer to the question "Do you participate in exercise or sports at a sport club?" over a span of four years. Three groups were identified: 1) adolescents who continued or started participating in organized sports, 2) adolescents who dropped out, and 3) adolescents who never participated or dropped out before reaching adolescence. Secondly, a multi-group latent growth curve model was estimated for cardiorespiratory and muscular fitness simultaneously in each of the three sport participation groups. Several model fit indices (RMSEA, TLI, CFI, SRMR) and their criteria were used to assess the goodness-of-fit of the model with the needed dataset. The criteria utilized were based on Hu & Bentler's (1999) recommendations. ANOVA with Tukey's post hoc analyses was used to determine whether there were significant differences in the means of the variables between the sport participation groups.

5 OVERVIEW OF THE RESULTS

This chapter provides a summary of the findings from studies I-IV, starting with the means and percentages of MVPA, BMI, and sport participation, which are presented in Table 5.

TABLE 5 Means, standard deviations and percentiles of MVPA, BMI and sport participation.

Measurement	Time	Total n	Mean (SD) /percentile
Total MVPA minutes per day / at least 60 min per day (%)	2017	452	58.78 (22.96) / 43.6%
	2018	286	55.05 (20.81) / 36.7%
	2019	208	52.90 (21.75) / 33.7%
	2020	131	57.28 (25.60) / 37.4%
	2021	70	51.64 (24.20) / 34.3%
BMI / overweight or obese (%)	2017	1120	18.88 (3.12) / 22.4%
	2018	1021	19.56 (3.41) /22.5%
	2019	839	20.31 (3.35) /21.5%
	2020	648	21.00 (3.36) /21.3%
	2021	580	21.43 (3.21) /23.5%
Participation in organized sports (%)	2017	1100	61.1%
	2018	1006	59.7%
	2019	892	55.8%
	2020	797	50.1%
	2021	781	38.7%
Maturation status	2017	1107	-1.30 (.80)
	2018	1071	-.38 (.85)
	2019	839	.54 (.90)
	2020	648	1.40 (.86)
	2021	577	2.24 (.80)

The outcomes of the simultaneous latent growth curves and latent profiles for the primary study variables are then presented, and the results related to the motor competence profiles and the trajectories of MVPA and cardiorespiratory fitness are discussed. The chapter ends with a summary of the findings on the association between participation in organized sports and cardiorespiratory fitness, muscular fitness, and BMI.

5.1 Developmental associations between motor competence, perceived motor competence, cardiorespiratory fitness, MVPA, and BMI from early to middle adolescence

In Study I, the primary aim was to examine the reciprocal associations between the developmental trajectories of motor competence, perceived motor competence, cardiorespiratory fitness, MVPA, and BMI from late childhood (age 11) to early adolescence (age 14). The descriptive results are presented in Table 6.

TABLE 6 Means and standard deviations of study variables in Study I.

Measurement	Time-point	n	Mean (SD)
Motor Competence (throws 0–20)	T0	1107	10.40 (5.27)
	T1	943	12.85 (4.73)
	T2	867	10.96 (4.88)
	T3	782	12.91 (4.80)
Perceived motor competence (Likert 1–5, revised)	T0	1096	3.48 (.82)
	T1	1003	3.47 (.88)
	T2	882	3.39 (.93)
	T3	826	3.42 (.95)
Cardiorespiratory fitness (20-meter lines)	T0	1058	36.07 (18.33)
	T1	943	40.47 (20.37)
	T2	769	39.15 (19.70)
	T3	674	44.12 (22.00)
MVPA (min/day)	T0	453	58.81 (22.94)
	T1	286	55.05 (20.81)
	T2	209	52.97 (21.73)
	T3	131	57.28 (25.60)
BMI (kg/m^2)	T0	1121	18.88 (3.12)
	T1	1022	19.56 (3.41)
	T2	840	20.31 (3.35)
	T3	649	21.00 (3.36)

To examine the longitudinal associations among the five variables, a parallel latent growth curve model was utilized. The model showed acceptable fit to the data ($\chi2$ (125) = 593.85, $p < .001$, CFI = .942, TLI = .921, RMSEA = .057, 90% Confidence interval (CI) [.052, .061], SRMR = .055). The results of the parallel latent growth curve model are presented in Table 7.

TABLE 7 Levels and slopes of parallel latent growth curves in Study I.

	Motor competence	Perceived motor competence	Cardio-respiratory fitness	MVPA	BMI
Level (SE)	10.93 (.16) ***	3.47 (.02) ***	36.12 (.53) ***	57.94 (.94) ***	18.89 (.98) ***
Slope (SE)	.57 (.06) ***	-.04 (.01)**	1.90 (.19) ***	-3.11 (.69) ***	.83 (.03) ***

Note 1. ***p < .001, **p < .01, *p < .05.

Over the 3-year period, the slopes indicate that motor competence, cardiorespiratory fitness, and BMI significantly increased, while perceived motor competence and physical activity decreased. Moreover, a significant variation between individuals was observed in the levels and slopes of each variable, indicating that individual trajectories diverged across the study population (see Figure 5 and original publication of study I).

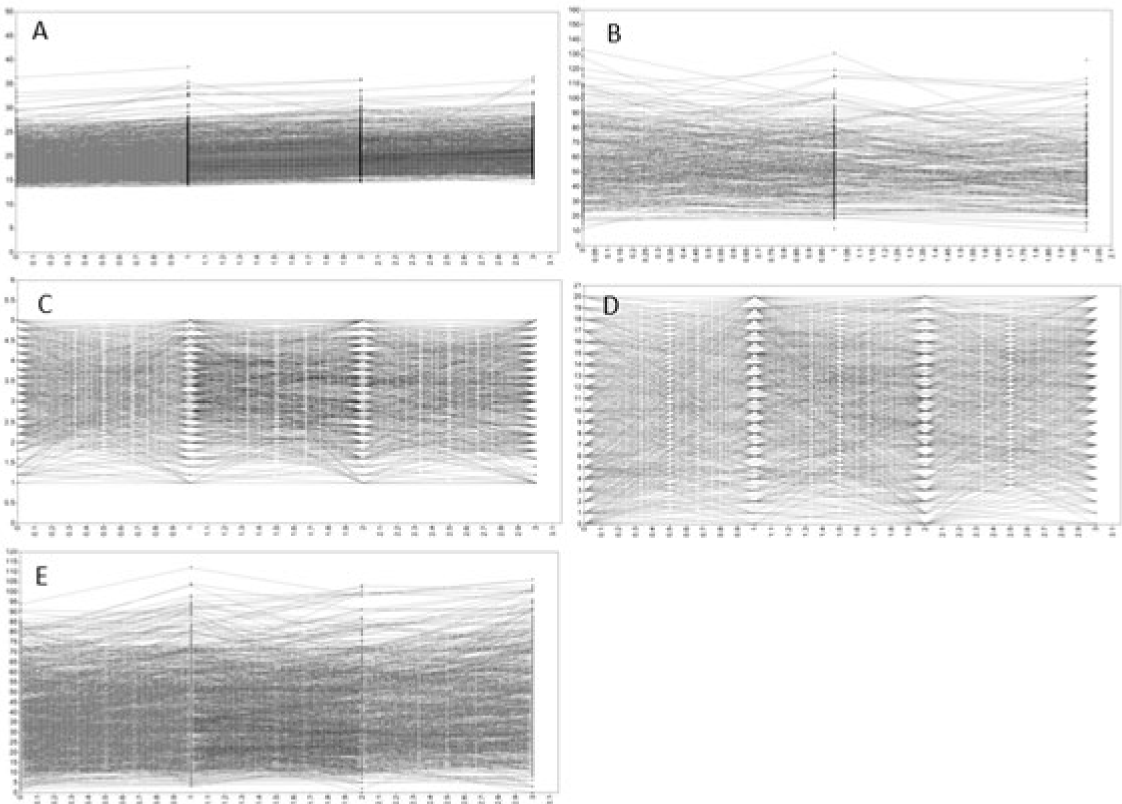


FIGURE 5 Individual trajectories of A) BMI, B) MVPA, C) Perceived motor competence, D) Motor competence, and E) Cardiorespiratory fitness in Study I.

The analysis revealed a negative association between the slopes of MVPA and BMI ($r = -.281$, $p < .05$), indicating that a decrease in MVPA over time was associated with an increase in BMI. This implies that the greater the decrease in MVPA, the larger the increase in BMI. A similar trend was found between the slopes of cardiorespiratory fitness and BMI ($r = -.467$, $p < .001$). However, despite the increase in both cardiorespiratory fitness and BMI, the negative association suggests that as BMI increases, the increase in cardiorespiratory fitness becomes smaller. This implies that a larger increase in BMI hinders improvement in cardiorespiratory fitness, and/or vice versa (less improvement in cardiorespiratory fitness leads to a larger increase in BMI). In addition, the slopes of cardiorespiratory fitness were positively associated with the slopes of actual ($r = .379$, $p <.05$) and perceived motor competence ($r = .405$, $p < .001$). This indicates that a greater increase in cardiorespiratory fitness was related to larger improvements in actual motor competence and smaller decline in perceived motor competence. Furthermore, significant associations were observed between the initial levels of the variables. For example, a positive association was found between levels of motor competence and MVPA ($r = .504$. $p < .005$), indicating that higher levels of motor competence were associated with higher baseline levels of MVPA.

5.2 Profiles of children based on their motor competence, perceived motor competence, cardiorespiratory fitness, MVPA and weight status, and the stability of their profile memberships over time

In Study II, the primary aim was to identify profiles of children based on their actual and perceived motor competence, cardiorespiratory fitness, MVPA and weight status, and then examine the stability of these profiles. Latent profile analysis was used to identify different profiles among the children, while latent transition analysis was used to investigate the stability of these profiles. Three profiles were identified: overweight/obese with low movement (OW-OB/MOVE-), normal weight with low movement (NW/MOVE-), and normal weight with high movement (NW/MOVE+) (see Table 8). The descriptive statistics for each profile are presented in Table 9.

TABLE 8 Profile prevalences, the number of adolescents, and gender distribution over four time points on profiles in Study II.

Profile prevalence / n				girls / boys (n)			
Time	Ow-Ob /Move-	Nw/ Move-	Nw/ move+	Time	Ow-Ob /Move-	Nw/ Move-	Nw/ move+
T0	.21/249	.40/456	.39/448	T0	123 / 123	283 / 173	177 / 268
T1	.22/256	.40/465	.38/441	T1	128 / 125	281 / 175	174 / 264
T2	.23/263	.41/475	.37/424	T2	129 / 131	288 / 178	166 / 255
T3	.23/261	.41/480	.36/421	**T3**	133 / 126	285 / 185	165 / 253

TABLE 9 Descriptives for profiles at each time point in Study II.

Measurement	Time	OW-OB/MOVE- M (SD)	NW/MOVE- M (SD)	NW/MOVE+ M (SD)
Object control skills: throw-catch combination test	T0	8.84 (.33) **(2,3)**	7.88 (.23) **(1,3)**	13.75 (.19) **(1,2)**
	T1	11.67 (.33) **(2,3)**	10.53 (.22) **(1,3)**	15.82 (.17) **(1,2)**
	T2	9.54 (.39) **(3)**	9.13 (.25) **(3)**	13.84 (.21) **(1,2)**
	T3	11.76 (.37) **(2,3)**	10.68 (.26) **(1,3)**	15.95 (.18) **(1,2)**
Locomotor skills: 5-leap test	T0	7.12 (.05) **(2,3)**	7.46 (.03) **(1,3)**	8.35 (.03) **(1,2)**
	T1	7.42 (.06) **(2,3)**	7.89 (.04) **(1,3)**	8.90 (.04) **(1,2)**
	T2	7.79 (.08) **(2,3)**	8.23 (.05) **(1,3)**	9.35 (.05) **(1,2)**
	T3	8.13 (.08) **(2,3)**	8.59 (.06) **(1,3)**	9.87 (.06) **(1,2)**
Locomotor skills: lateral jump test	T0	68.35 (.87) **(3)**	70.40 (.55) **(3)**	82.00 (.52) **(1,2)**
	T1	71.80 (.90) **(2,3)**	75.72 (.63) **(1,3)**	88.32 (.57) **(1,2)**
	T2	79.47 (1.04) **(2,3)**	84.25 (.65) **(1,3)**	98.32 (.65) **(1,2)**
	T3	85.20 (1.20) **(2,3)**	88.98 (.73) **(1,3)**	101.78 (.72) **(1,2)**
Cardiorespiratory Fitness: 20-meter shuttle run test	T0	20.40 (.71) **(2,3)**	28.63 (.57) **(1,3)**	52.11 (.72) **(1,2)**
	T1	23.46 (.87) **(2,3)**	32.01 (.69) **(1,3)**	57.06 (.88) **(1,2)**
	T2	23.09 (.96) **(2,3)**	31.32 (.64) **(1,3)**	55.61 (1.03) **(1,2)**
	T3	26.79 (1.26) **(2,3)**	35.30 (.87) **(1,3)**	62.33 (1.14) **(1,2)**
Perceived motor competence (Likert 1–5, revised)	T0	3.15 (.04) **(3)**	3.20 (.03) **(3)**	3.94 (.04) **(1,2)**
	T1	3.01 (.06) **(3)**	3.07 (.04) **(3)**	4.09 (.03) **(1,2)**
	T2	2.90 (.06) **(3)**	2.99 (.04) **(3)**	4.09 (.04) **(1,2)**
	T3	3.05 (.06) **(3)**	2.95 (.04) **(3)**	4.14 (.04) **(1,2)**
MVPA (min/day)	T0	48.23 (1.96) **(3)**	48.91 (1.28) **(3)**	72.56 (1.63) **(1,2)**
	T1	46.08 (3.09) **(3)**	47.57 (1.50) **(3)**	65.09 (1.81) **(1,2)**
	T2	45.89 (3.91) **(3)**	43.38 (1.97) **(3)**	62.48 (2.08) **(1,2)**
	T3	46.26 (4.46) **(3)**	46.99 (2.41) **(3)**	69.72 (3.58) **(1,2)**
Percentages of weight statuses (%)	T0	Ow: 81.55, Ob: 18.45	T: 6.21, N: 90.34, Ow: 3.45	T: 5.01, N: 94.99
	T1	Ow: 79.40, Ob: 20.60	T: 8.86, N: 89,06, Ow: 2.04	T: 9.00, N: 86.75, Ow: 4.25
	T2	Ow: 77.11, Ob: 22.89	T: 8.36, N: 91.64	T: 4.10, N: 92.74, Ow: 3.15
	T3	Ow: 84.38, Ob: 15.63	T: 7.45, N: 92.55	T: 4.45, N: 93.12, Ow: 2.43

Note 1. Bolded numbers (1 = ow-ob/move-, 2 = nw/move-, 3 = nw/move+) indicate the profiles between which a significant difference ($p < .05$) was observed.
Note 2. T = thinness, N = normal weight, Ow = overweight, Ob = obesity (Cole & Lobstein, 2012).

Participants in the OW-OB/MOVE- profile were predominantly overweight or obese. They also demonstrated the lowest scores in cardiorespiratory fitness and locomotor skills tests compared to the other two groups. Aside from this, the participants in the NW/MOVE- profile shared similarities with those in the OW-OB/MOVE- profile. The participants in these two profiles showed similar scores in MVPA and perceived motor competence. However, the children in the OW-

OB/MOVE- profile demonstrated higher scores in object control competence at three of the four time points. In contrast, the adolescents in the NW/MOVE+ profile were mostly within the normal weight range for their age and achieved the highest scores in all measurements, except for BMI, when compared to the other two profiles. Profile characteristics are illustrated in Figure 6.

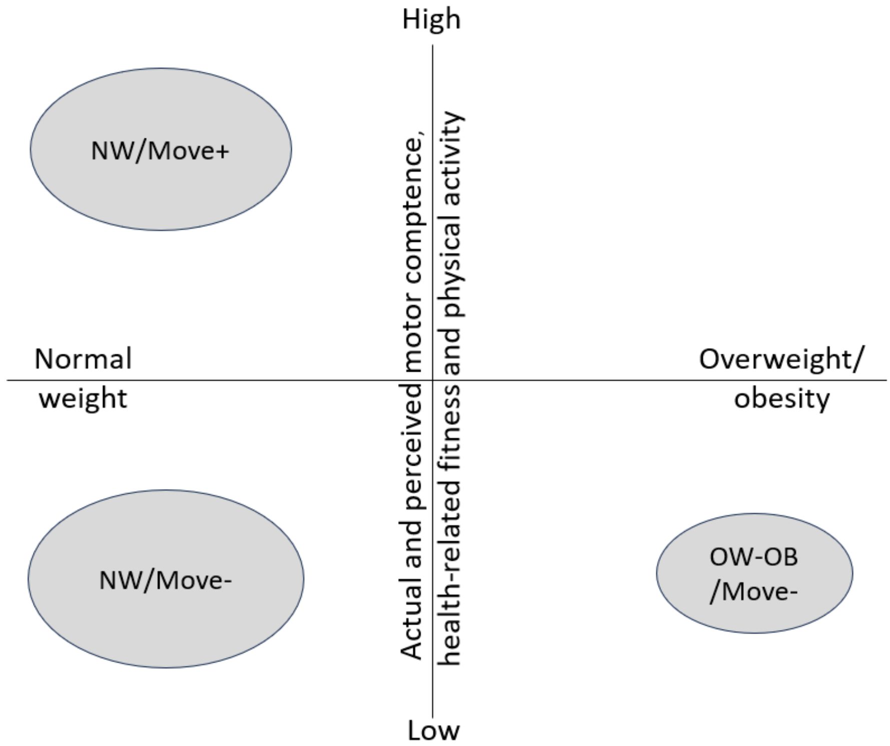


FIGURE 6 Profile characteristics in Study II.

The latent transition analysis showed that the probabilities of transitioning from one profile to another over time were small, less than 20% (see Table 10). This demonstrates a high degree of stability, with characteristics remaining consistent from ages 11 to 14. For instance, adolescents who have low actual and perceived motor competence and engage in low levels of physical activity at age 11 are likely to continue exhibiting these characteristics at age 14. The results indicated that at two time points (T0 and T2), girls were more likely to be in a NW/MOVE- profile than the other two profiles.

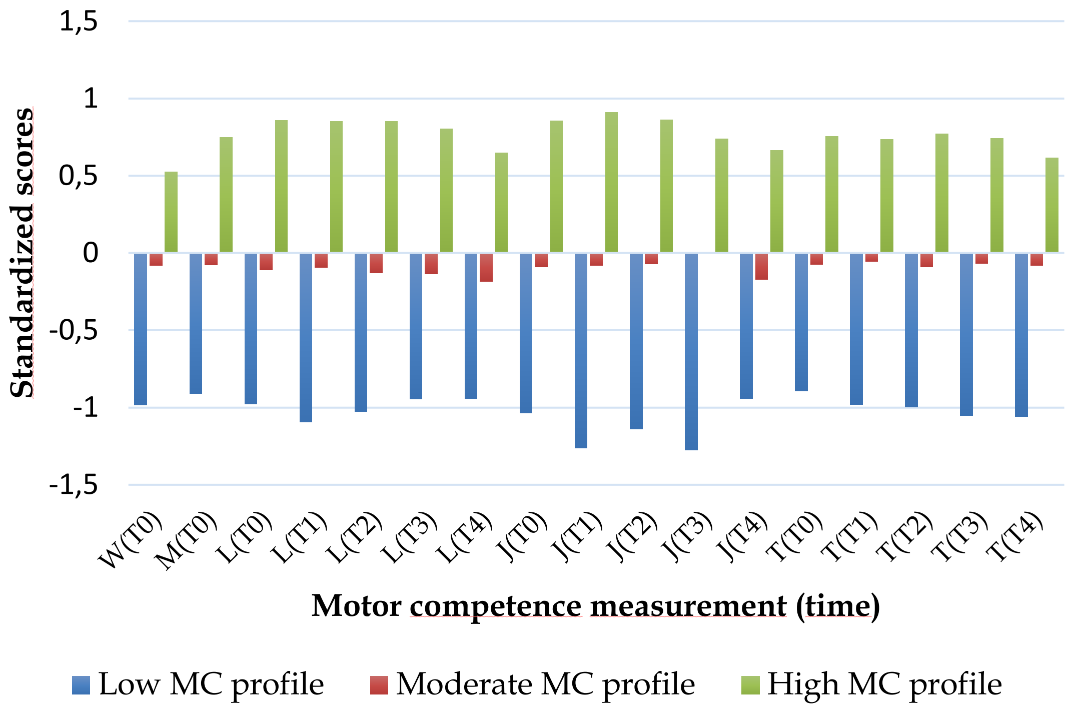
TABLE 10 Transition probabilities over four time points on profiles in Study II.

	From T0 to T1				From T1 to T2				From T2 to T3		
	Ow-Ob /Move-	Nw/ Move-	Nw/ move+		Ow-Ob /Move-	Nw/ Move-	Nw/ move+		Ow-Ob /Move-	Nw/ Move-	Nw/ move+
Ow-Ob /Move-	.92	.08	.00	Ow-Ob /Move-	.83	.09	.08	Ow-Ob /Move-	.81	.17	.02
Nw/ Move-	.07	.93	.00	Nw/ Move-	.07	.93	.00	Nw/ Move-	.07	.91	.02
Nw/ move+	.01	.02	.97	Nw/ move+	.03	.06	.91	Nw/ move+	.03	.00	.97

Note 1. Bolded value under transition probability indicates a probability of > .80.
Note 2. Profiles in earlier years are shown in rows and profiles in successive years in columns.

5.3 Motor competence profiles and their associations with trajectories of cardiorespiratory fitness and MVPA

In Study III, the main objective was to identify longitudinal motor competence profiles and examine four-year trajectories of MVPA and cardiorespiratory fitness in each profile. Distinct profiles among the children were identified using latent profile analysis, and the trajectories of MVPA and cardiorespiratory fitness in each identified profile were examined using latent growth curve modeling. Three motor competence profiles were identified: low (21% of the sample), moderate (49%), and high (30%). Figure 7 shows the mean standardized scores of the motor competence measurements for each profile. All the observed differences in motor competence scores between the identified profiles were statistically significant. The profiles showed no significant differences in maturation status.



W = Walking backwards, M = Moving sideways, L = 5-leaps, J = Lateral jump, T = Throw-catch combination.

FIGURE 7 Standardized motor competence scores of the adolescents in each motor competence profile in Study III.

The latent growth curves were estimated simultaneously for each of the three motor competence profiles in order to analyze the initial levels and slopes in MVPA and cardiorespiratory fitness (see Table 11). The results indicated significant differences in the initial levels of MVPA and cardiorespiratory fitness between the motor competence profiles. Levels were lowest in the low motor competence profile and highest in the high motor competence profile.

TABLE 11 Levels and slopes of MVPA and cardiorespiratory fitness for each motor competence profile in Study III.

Measurement		Low motor competence profile M (SE)	Moderate motor competence profile M (SE)	High motor competence profile M (SE)
MVPA	Level (SD)	44.82 (1.46) ***	56.67 (1.56)***	70.13 (1.89)***
	Slope (SD)	.89 (.18)	-1.44 (1.14)	-3.36 (.73)***
Cardiorespiratory fitness	Level (SD)	20.00 (.11)***	34.94 (.83)***	52.00 (1.04)***
	Slope (SD)	1.20 (.14)**	1.28 (.29)***	2.21 (.52) ***

Note 1. ***p < .001, **p < .01, *p < .05.

The high MC profile exhibited a significant negative slope in MVPA, indicating that MVPA decreased significantly over time. In contrast, MVPA remained stable in the other two profiles (see Figures 8 and 9). The slopes of cardiorespiratory fitness within each motor competence profile showed a statistically significant increase over time. However, no significant differences in the slopes were found between the profiles, indicating a similar rate of improvement in cardiorespiratory fitness in each profile. A correlation was found between the slopes of MVPA and cardiorespiratory fitness (r = .646, p = .001) in the high motor competence profile. This suggests that the steeper the decrease in MVPA, the lower the improvement in cardiorespiratory fitness.

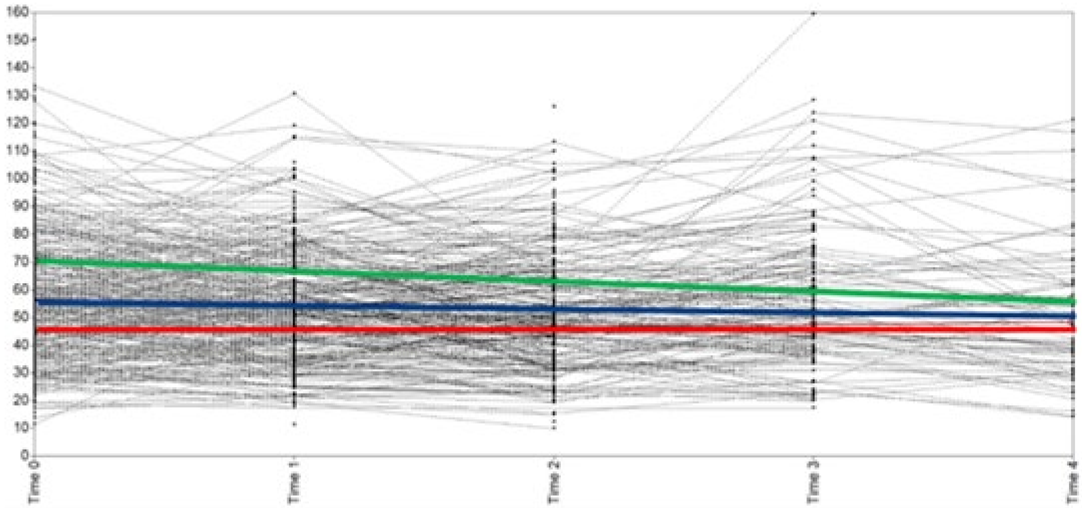


FIGURE 8 Development of MVPA in the low (red), moderate (blue) and high (green) motor competence profiles in Study III.

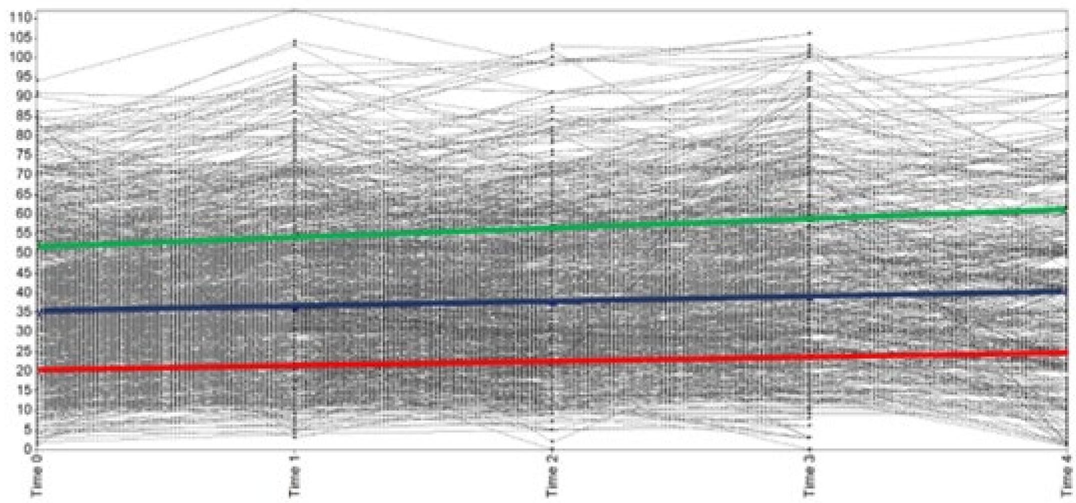


FIGURE 9 Development of cardiorespiratory fitness in the low (red), moderate (blue) and high (green) motor competence profiles in Study III.

5.4 Association of organized sport participation with health-related fitness

In Study IV, the main objective was to examine the effect of organized sport participation on cardiorespiratory fitness, muscular fitness, and BMI. First, participants were divided into three groups based on their organized sport participation status overtime: 1) those who continued or started participating in organized sports, 2) those who dropped out, and 3) those who never participated or who dropped out before adolescence. Descriptive statistics for each group are presented in Table 12. There were no significant differences between the groups in maturation status.

TABLE 12 Descriptives of study variables in Study IV.

Measurement	Time	n	Participant-group M (SD)	Dropout-group M (SD)	Non-participant-group M (SD)
BMI	T0	942	18.60 (2.71) N	18.67 (2.93) N	19.61 (3.90) P,D
	T2	802	20.03 (2.88)	20.38 (3.52)	20.70 (3.92)
	T4	559	21.31 (2.62)	21.49 (3.60)	21.68 (3.96)
Cardiorespiratory fitness (Laps completed)	T0	889	41.52 (18.68) D,N	34.63 (15.80) P,N	26.88 (14.76)
	T2	719	45.40 (20.39) D,N	35.64 (16.71) P,N	29.84 (15.47)
	T4	409	49.75 (21.62) D,N	34.37 (18.84) P	33.43 (18.01) P
Muscular fitness (Push-ups in 60 seconds)	T0	907	24.16 (12.06) D,N	21.79 (11.61) P,N	15.78 (11.82)
	T2	797	29.44 (12.72) D,N	24.35 (11.91) P,N	18.17 (12.39)
	T4	479	33.65 (12.93) D,N	25.86 (12.59) P	23.66 (11.88) P

Note 1. Letters (P = participant group, D = dropout group, N = non-participant group) indicate the profiles between which a significant difference ($p < .05$) was observed.

Second, a multi-group parallel latent growth curve model was employed to examine the trajectories of cardiorespiratory fitness, muscular fitness, and BMI over a four-year period for each group. The results showed significant differences in the initial levels of cardiorespiratory and muscular fitness among all three groups. Adolescents who continued their participation in organized sports over the five-year period had the highest initial levels of both cardiorespiratory and muscular fitness. The group of adolescents who dropped out from organized sports had the second highest initial levels, while the group of adolescents who did not participate in organized sports at all during the four-year period had the lowest initial levels. Additionally, the initial BMI level was significantly higher in adolescents who did not participate in organized sports than their peers in the other two groups. Those who continued their participation in organized sports over the four-year period and those who did not participate showed positive and significant improvements in cardiorespiratory fitness. Importantly, there was no significant difference in the slopes between these two groups, indicating a similar rate of increase in cardiorespiratory fitness (see Table 13).

TABLE 13 Levels and slopes of cardiorespiratory fitness, muscular fitness, and BMI for each sport participation group in Study IV.

		Participant-group (P)	Dropout-group (D)	Non-participant - group (N)
Cardiorespiratory fitness	Level (SE)	41.45 (.83)*** (D,N)	34.74 (.92)*** (P,N)	26.84 (1.03)*** (P,D)
	Slope (SE)	1.54 (.29)*** (D)	-.23 (.40) (P,N)	1.27 (.39)*** (D)
Muscular fitness	Level (SE)	24.02 (.53)*** (D,N)	21.77 (.70)*** (P,N)	15.74 (.76)*** (P,D)
	Slope (SE)	2.40 (.19)*** (D)	1.06 (.23)*** (P,N)	1.97 (.27)*** (D)
BMI	Level (SE)	18.60 (.12)*** (N)	18.68 (.17)*** (N)	19.59 (.28)*** (P.D)
	Slope (SE)	.73 (.03)***	.81 (.04)***	.70 (.09)***

Note 1. $^{***}p < .001$, $^{**}p < .01$, $^{*}p < .05$.
Note 2. Letters (P = participant group, D = dropout group, N = non-participant group) indicate the profiles between which a significant difference (p < .05) was observed.

However, among the adolescents who dropped out of organized sports, no significant change was found in cardiorespiratory fitness over time, as indicated by the non-significant slope. At the final time point, no significant differences were found in the mean values of cardiorespiratory fitness between children who dropped out and adolescents who had not participated in organized sports. Muscular fitness exhibited positive and significant changes in the slopes of all three groups. However, the rate of change was significantly lower among children who had dropped out of organized sports compared to their peers in the other two groups. Similarly, at the final time point, the mean values of muscular fitness showed no significant differences between the adolescents who had dropped out and those who had never participated in organized sports. The slopes for BMI were positive and significant in all three groups, indicating a consistent increase in BMI over time. Moreover, no significant differences were observed between the groups, indicating a comparable rate of change. The results of the multi-group parallel latent growth curve models are illustrated in Figures 10, 11, and 12.

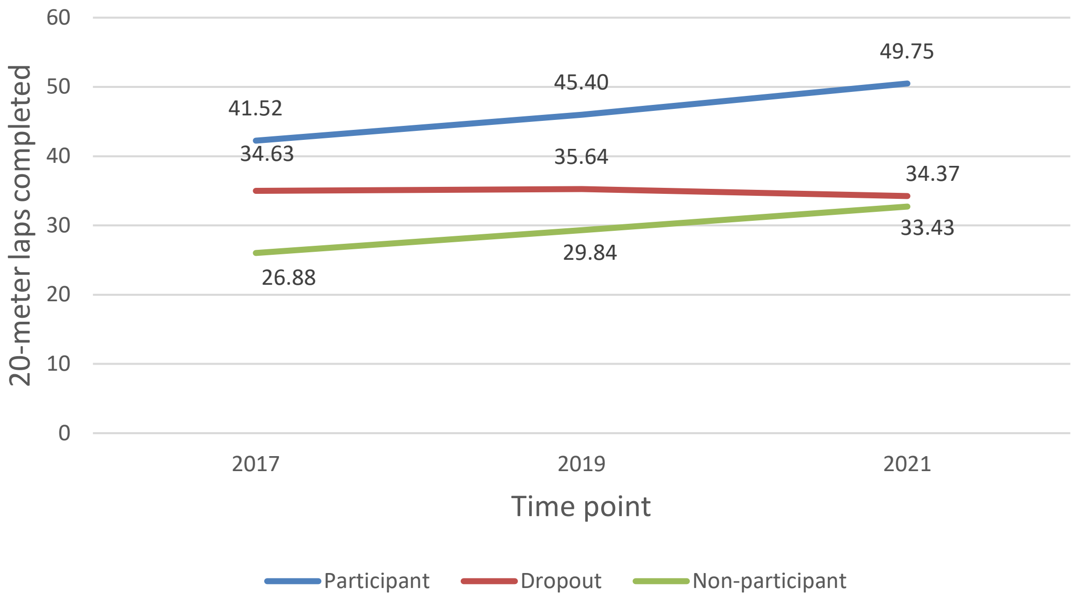


FIGURE 10 Trajectories of cardiorespiratory fitness for each sport participation group (mean scores are presented) in Study IV.

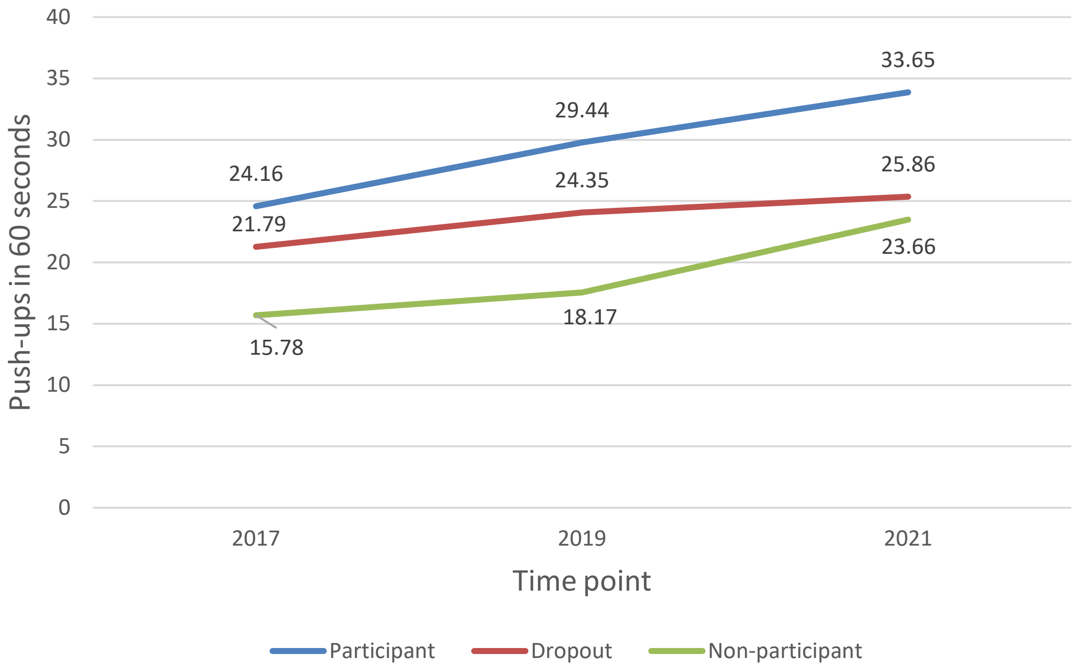


FIGURE 11 Trajectories of muscular fitness for each sport participation group (mean scores are presented) in Study IV.

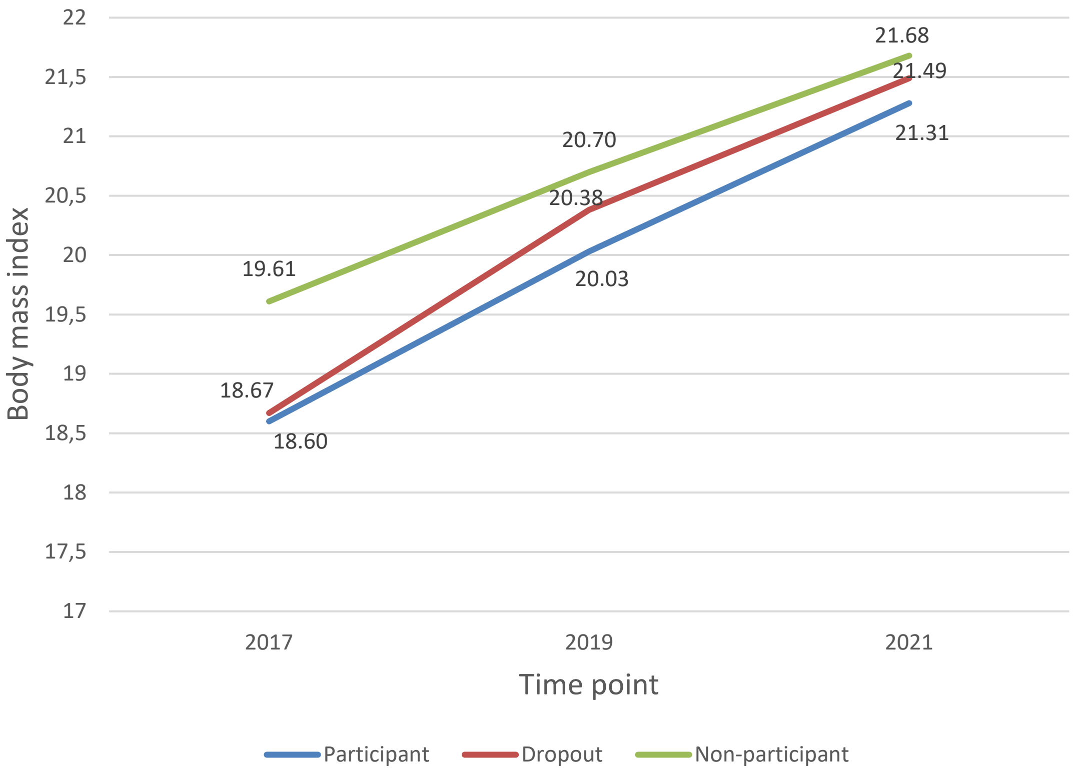


FIGURE 12 Trajectories of BMI for each sport participation group (mean scores are presented) in Study IV.

6 DISCUSSION

6.1 Main findings

In Study I, the objective was to investigate developmental changes in motor competence, perceived motor competence, cardiorespiratory fitness, MVPA, and BMI during adolescence. Specifically, the primary aim was to analyze the associations between the developmental changes in the five variables. The main finding of the study was that a higher increase in BMI was associated with a larger decrease in MVPA and lower rate of improvement in cardiorespiratory fitness. In addition, a significant improvement in cardiorespiratory fitness was positively associated with changes in both actual and perceived motor competence. However, the development of MVPA was not significantly associated with the improvement of cardiorespiratory fitness or motor competence.

In Study II, the primary objective was to identify distinct profiles based on motor competence, perceived motor competence, cardiorespiratory fitness, MVPA and BMI, and to examine the stability of these profiles over time. The key finding of the study was the identification of three distinct profiles, each of which exhibited relative stability throughout the observation period. The first profile supported the positive spiral of engagement in physical activity proposed by Stodden et al. (2008). The children in this profile demonstrated significantly higher levels of motor competence, perceived motor competence, physical activity, and cardiorespiratory fitness compared to peers in the other two profiles. Moreover, these children were mostly of normal weight. The other two profiles showed similar levels of physical activity and perceived motor competence. However, while the children in the second profile were predominantly of normal weight, those in the third profile were mostly overweight or obese. Moreover, the children in the third profile demonstrated the lowest levels of locomotor competence and cardiorespiratory fitness. This could potentially be attributed to the additional weight burden associated with being overweight or obese.

In Study III, the objectives were, first, to identify children based on their levels of motor competence over time and, second, to examine the patterns of physical activity and cardiorespiratory fitness in each of the identified groups. Three distinct motor competence profiles, characterized as low, moderate, and high, were identified. Each of the three profiles exhibited different initial levels of physical activity and cardiorespiratory fitness that corresponded to their motor competence profile labels. Furthermore, the trajectories of cardiorespiratory fitness remained distinct between the profiles over time, indicating that the initial differences were maintained throughout the observation period. However, in their physical activity, the adolescents in the profiles of low and moderate motor competence did not show significant changes over time. In contrast, the adolescents in the group with high motor competence demonstrated a significant decline in their physical activity levels over time.

In Study IV, the main objective was to examine the development of health-related fitness and BMI among adolescents who had continued or started participating in organized sports, those who had dropped out, and those who had never participated or had dropped out before adolescence. The children in the continuous and dropout groups demonstrated higher initial levels of health-related fitness compared to their non-participating peers. The main finding was that both the continuous and non-participating groups showed positive development in cardiorespiratory and muscular fitness over time. However, the dropout group had significantly smaller improvements in muscular fitness and did not show any improvements in cardiorespiratory fitness. By the final time point, significant differences in cardiorespiratory and muscular fitness levels were no longer existed between the dropout group and the non-participating group.

6.2 Developmental associations of motor competence, perceived motor competence, health-related fitness, physical activity, and weight status from early to middle adolescence

A few previous studies have examined the developmental associations between the five variables of motor competence, perceived motor competence, health-related fitness, physical activity, and weight status (Coppens et al., 2019; Rodrigues et al., 2016; Estevan et al., 2021). However, this was the first study to examine their development simultaneously over multiple time points in adolescence. The results of Study I showed that motor competence, health-related fitness, and BMI increased during adolescence, while perceived motor competence and physical activity decreased. These trends support previous findings (Cole & Lobstein, 2012; Farooq et al., 2020; Barnett et al., 2016; Raghuveer et al., 2020; Baker & Davison, 2011) suggesting that adolescents MVPA and perceived motor competence decline over time, whereas their cardiorespiratory fitness and actual motor competence improve. Improvements in cardiorespiratory fitness and actual motor competence are also partly attributable to maturation and growth (Raghuveer et al., 2020; Goodway et al., 2021), while the decrease in perceived motor competence may partly be associated with an increased cognitive capability to assess one's own competence more accurately (Horn & Weiss, 1991). However, it is important to note the significant inter-individual variation found in both the levels and slopes of these variables. This indicates the existence of diverse trajectories within individual adolescents, as also reported in previous studies (Coppens et al., 2019; Raghuveer et al., 2020; De Meester et al., 2016; Oluwagbemigun et al., 2019; Lounassalo et al., 2019). This variation may partly be explained by differences in the timing and tempo of maturation during adolescence (Malina et al., 2004). However, the approach used in Study I allows a closer examination of these developmental differences. It addresses questions such as whether larger improvements in motor competence are associated with changes in physical activity. The findings of Study 1 supported several longitudinal associations posited in the conceptual model of Stodden et al. (2008). These included a positive developmental association between changes in motor competence and health-related fitness, as well as a negative developmental association between changes in physical activity and weight status, and in health-related fitness and weight status (Stodden et al., 2008). It should be noted that maturation was not considered in the analysis, which leaves room for further investigation into whether maturation contributes to the associations between variables and the intra-individual variation within these variables (Malina et al., 2004).

Motor competence, as measured by the throw-catch combination test, and health-related fitness, as measured by cardiorespiratory fitness, were found to be associated both at the initial levels and longitudinally. Thus, the greater the improvement in motor competence, the greater the improvement in cardiorespiratory fitness over time. This finding is consistent with the results of a meta-analysis conducted by Utesch et al. (2019), which demonstrated a moderate to large association between motor competence and health-related fitness. However, , this finding for object-control skills contradicts the results of a recent systematic review on the various domains of motor competence. In their review, Barnett et al. (2022) found robust positive evidence supporting the pathway from locomotor skills to health-related fitness and fitness, as well as the reverse. However, there was insufficient evidence on the impact of object-control skills. As discussed in the meta-analysis conducted by Utesch et al. (2019), there is likely an overlap between motor competence and health-related fitness, which can be partially explained by similar neuromuscular demands (Utesch et al., 2019). Study I found evidence of a longitudinal association between object-control skills and cardiorespiratory fitness, although it did not establish causality. This supports the conceptual model proposed by Stodden et al. (2008), according to which higher levels of motor competence and cardiorespiratory fitness may promote participation in vigorous physical activities, such as ball games

(Robinson et al., 2015; Ré et al., 2016). Such activities, in turn, promote fitness and provide additional opportunities to enhance motor competence (Stodden et al., 2008). However, Study I did not find any evidence to support the hypothesized longitudinal association between motor competence and physical activity.

The association between motor competence, specifically object-control skills, and physical activity was initially significant and positive. This suggests that in the baseline year of 2017, adolescents with higher motor competence exhibited higher levels of MVPA, which aligns with findings from previous studies (Robinson et al., 2015). However, as the adolescents progressed through the study, the development of their motor competence was not associated with changes in their MVPA. This finding aligns with a recent systematic review by Barnett et al. (2022), which also reported a lack of longitudinal evidence supporting a relationship between motor competence and physical activity. During adolescence, physical activity typically declines, as confirmed in Study I. Furthermore, the results indicated that while adolescents with higher initial levels of motor competence also had higher initial levels of MVPA, they showed a steeper decline in MVPA over time. These findings suggest that although linked to increased physical activity at the age of 11, higher motor competence may not be sufficient to offset the decrease in physical activity that commonly happens during adolescence (Farooq et al., 2020), particularly among the most active adolescents (Lounassalo et al., 2019). There are many reasons why, despite improvements in motor competence, physical activity may decline during adolescence (Bélanger et al., 2012). For example, many adolescents drop out of organized sports (Kokko et al., 2019) and may, as they become increasingly influenced by their social surroundings, such as friends, prioritize their time differently (Maturo & Cunningham, 2013). However, the absence of a developmental association between motor competence and MVPA does not rule out the possibility that higher motor competence has a positive impact on physical activity during adolescence. This topic is explored in greater detail and discussed further in Study III.

Interestingly, the development of physical activity was not associated with the development of cardiorespiratory fitness. This indicates that adolescents who, for example, experienced a greater decline in MVPA did not demonstrate less improvement in cardiorespiratory fitness. However, the initial levels of the two variables were positively correlated, indicating that at the age of 11, adolescents who demonstrated higher cardiorespiratory fitness also demonstrated higher levels of MVPA. A similar longitudinal association was observed by Telford, Telford, Cochrane et al. (2016). They found that adolescents showed a decrease in physical activity while simultaneously demonstrating an increase in cardiorespiratory fitness. It is important to note that cardiorespiratory fitness naturally increases during adolescence due to maturation and growth (Raghuveer et al., 2020; Malina et al., 2004). Specifically, fat-free mass, which is the most significant factor influencing cardiorespiratory fitness, increases significantly between the ages of 11 and 15 in both girls and boys (Armstrong & Welsman, 2019a). The morphological changes induced by maturation and growth may, despite the decrease in physical activity at least partially explain the overall increase in fitness (Raghuveer et al., 2020). Armstrong and Welsman (2019c) have also suggested that the absence of a meaningful relationship between physical activity and cardiorespiratory fitness in young people may be due to the insufficient intensity and duration of the kind of physical activity, i.e., vigorous physical activity, required to significantly enhance cardiorespiratory fitness. Therefore, the absence of an association between cardiorespiratory fitness and MVPA could indicate that the decline in MVPA predominantly occurred in activities of moderate intensity. However, further studies would be needed to confirm this hypothesis.

The development of BMI was inversely associated with the development of physical activity and cardiorespiratory fitness. This means that the larger the increase in BMI, the steeper the decline in physical activity and the smaller the improvement in cardiorespiratory fitness. The systematic review by Poitras et al. (2016) found conflicting evidence from longitudinal studies on the relationship between physical activity and adiposity outcomes. In their systematic review approximately half of the longitudinal studies that examined vigorous physical activity and/or MVPA reported a favorable prospective association with at least one measure of adiposity (Poitras et al., 2016). Thus, the present finding provides evidence for a possible bidirectional longitudinal relationship between physical activity and weight status. Physical activity increases energy expenditure and may therefore play a crucial role in maintaining a healthy weight (Westerterp, 2017). In contrast, weight gain may lead to a decline in physical activity (Hjorth et al., 2014) as it can cause faster fatigue due to the increased energy expenditure required for movement (Norman et al., 2005). Study I demonstrated that a greater increase in BMI was associated with less improvement in cardiorespiratory fitness, possibly due to reduced physical activity (Westerterp, 2017) or increased mechanical load from excess weight (Welsman & Armstrong, 2019). These mechanisms likely work together, promoting a self-perpetuating vicious circle of obesity, physical inactivity, and poor fitness (Pietiläinen et al., 2008; Richmond et al., 2014).

6.3 Distinct movement profiles and their stability over time

The conceptual model proposed by Stodden et al. (2008) suggests that children may experience either a positive spiral of engagement or a negative spiral of disengagement in physical activity over time. The model suggests that among children and adolescents, having high actual and perceived motor competence, high levels of fitness, and engaging in greater physical activity would promote the development of a healthy weight status (positive spiral). On the other hand, having low actual and perceived motor competence, poor fitness, and engaging in low levels of physical activity may lead to an unhealthy weight status, which in turn can further exacerbate the aforementioned variables (negative spiral) (Stodden et al., 2008). Previous studies by Jaakkola et al. (2020; 2021) and Estevan et al. (2021) have identified different profiles using the variables presented in the model developed by Stodden et al. (2008). However, none of these studies have used all five variables to identify profiles, but instead have considered physical activity and weight status as outcomes. In Study II, children were profiled based on their scores in all five variables at four different time points. The reason for including all the variables in the profiles, rather than treating some as outcomes, is the bidirectional nature of the associations which has been observed in previous studies (Barnett et al., 2022) and in Study I.

Three similar profiles were identified at each time point: "low movement with overweight/obesity," "low movement with normal weight," and "high movement with normal weight." The profile of high movement with normal weight demonstrated a positive spiral of engagement in physical activity, as suggested by Stodden et al. (2008). The adolescents in this profile had significantly higher scores in all measurements, except for BMI, compared to their peers in the other two profiles. A similar profile has been found by Estevan et al. (2021) and Jaakkola et al. (2020; 2021). These studies identified a profile of children with high levels of motor competence, perceived motor competence, physical activity (Jaakkola et al., 2020; 2021), and a lower BMI (Estevan et al., 2021). Together with these previous person-oriented studies, the findings from Study II support the positive cycle of engagement outlined in the Stodden et al. model (2008). The model posits that adolescents with elevated levels of both actual and perceived motor competence, and with high cardiorespiratory fitness, are more likely to engage in regular physical activity and maintain a healthy weight status during adolescence (Jaakkola et al., 2020; 2021; Estevan et al., 2021). The two additional profiles identified in Study II, namely the "low movement with overweight/obesity" and "low movement with normal weight" profiles, exhibited significantly lower levels of motor competence, perceived motor competence, health-related fitness, and physical activity compared to the "high movement with normal weight" profile. These findings align with the concept of a negative spiral of disengagement, which is consistent with the conceptual model proposed by Stodden et al. (2008). Adolescents with lower perceived and actual motor competence may be more inclined to withdraw from physical activity (V. P. Lopes et al., 2011), potentially hindering their fitness progress. However, when considering weight status, it is important to note that the "low movement with overweight/obesity" profile primarily consisted of children who were overweight, whereas the "low movement with normal weight" profile mainly included children who had a normal weight. This suggests that weight status is already a part of this negative cycle during adolescence, rather than solely an outcome, as posited for younger children in the Stodden et al. (2008) model.

Adolescents in the "low movement with overweight/obesity" profile showed lower scores in cardiorespiratory fitness and locomotor skills compared to their peers in the "low movement with normal weight" profile. Previous studies have consistently found that a higher BMI is associated with lower cardiorespiratory fitness (Armstrong & Welsman, 2019c) and locomotor competence (Webster et al., 2021). These observations suggest a possible explanation. Both cardiorespiratory fitness and locomotor skills require weight-bearing activities. It is possible that overweight and obesity may impose morphological limitations that impede the body's effective movement through space, especially against gravity. This idea is also supported by Chivers et al. (2013), Armstrong and Welsman (2019c), and Webster et al. (2021). However, it is essential to consider an alternative perspective, as being overweight may also potentially hinder the development of motor competence and cardiorespiratory fitness (Chivers et al., 2013; Lima et al., 2021). This, in turn, can result in lower motor competence scores during adolescence. However, the findings from Study II showed that children with overweight exhibited better object control skills compared to their normal weight counterparts in the other profile, as also demonstrated in a study by Webster et al. (2021) and Duncan et al. (2017). Plausible explanations for this could be that children who are overweight may have greater absolute muscular strength, which could potentially enhance their performance in tasks involving throwing (Thivel et al., 2016). Extra weight may also have a greater negative impact on skills that require movement of the entire body (e.g., 5-leaps) compared to those that involve only one side of the body (e.g., throwing), as suggested by Bryant et al. (2014). The findings from Study II, along with these previous observations, raise the question of whether the lower motor competence scores observed in overweight adolescents are primarily due to morphological limitations or a lack of engagement in physical activity and the development of motor competence. A recent extensive cross-sectional study by Martins et al. (2023) provided evidence that a higher BMI was associated with lower motor competence scores in early childhood, with this association being stronger at the higher end of the BMI distribution. The study assessed motor competence by evaluating the quality of movement, using a process-oriented assessment. It also examined both object control and locomotor skills (Martins et al., 2023). This type of motor competence assessment is less influenced by factors related to additional weight, such as the force of gravity. However, although the causal relationship between motor competence and weight status remains unclear, this could suggest that the negative correlation between overweight and motor skill quality already becomes apparent as early as age of four (Martins et al., 2023). This could potentially impact physical activity behavior, weight status, and motor competence in adolescence. Furthermore, as suggested by the findings of Study II, this may contribute to the formation of a self-perpetuating cycle where, as proposed by Robinson et al. (2015), poor motor competence is both a precursor and a consequence of overweight and obesity.

Typically, previous studies have compared children with normal weight to children who are overweight when examining actual and perceived motor competence, physical activity, or health-related fitness. These studies have consistently found that children who are overweight tend to show lower scores (Southall et al., 2004; D'Hondt et al., 2009; Jones et al., 2010; Artero et al., 2010; Gentier et al., 2013). However, in making such comparisons, we might overlook a potential risk group: children whose weight is normal but have lower levels of actual and perceived motor competence, lower levels of physical activity, and poorer fitness than their fitter and more active normal weight peers. Although the results of Study II mostly showed only a small proportion of transitions (less than 10%) between profiles over time, 17% of the adolescents transitioned from the 'low movement with overweight/obesity' profile to the 'low movement with normal weight' profile during the final year. This is likely due to a change in weight status from overweight to normal weight, which does not necessarily require much change if one is close to the cutoff point. The small proportion of transitions indicates that children with low actual and perceived motor competence, cardiorespiratory fitness, and physical activity in early adolescence tended to continue exhibiting these characteristics throughout adolescence. Moreover, previous longitudinal studies have shown that these characteristics also tend to persist from adolescence into adulthood (Telama et al., 2009; Singh et al., 2008; True et al., 2021; García-Hermoso et al., 2022). It is important to acknowledge this as, according to the conceptual model of Stodden et al. (2008), these children may be at risk for unhealthy weight development and low physical activity in the future.

6.4 The role of motor competence for physical activity and cardiorespiratory fitness

While it is widely acknowledged that motor competence plays a crucial role in shaping a physically active lifestyle (Seefeldt, 1980; Seefeldt & Haubenstricker, 1987; Stodden et al., 2008; Robinson et al., 2015), it is important to recognize that the evidence supporting this assertion is neither definitive nor conclusive (Barnett et al., 2022). While Study I showed no association between the development of motor competence and physical activity, it demonstrated a relationship at the initial level. Moreover, Study II revealed that characteristics such as poor motor competence, low fitness, and low physical activity tend to be clustered within the same individuals and persist throughout adolescence. This raises the question of whether adolescents with varying levels of motor competence would also exhibit different patterns of physical activity and cardiorespiratory fitness throughout adolescence. For example, Seefeldt and Haubenstricker (1987) suggested that an adequate level of motor competence is important for promoting successful participation in physical activities. Moreover, they proposed that children who fall below this threshold, often referred to as the "motor proficiency barrier", a term coined by Seefeldt in 1980, may be at a greater risk of being inactive or experiencing challenges in effectively participating in physical activities. It should be noted that motor skill learning tends to be a relatively stable and cumulative process (Magill & Anderson, 2017), unlike fitness and physical activity, which can change over time due to various behavioral and physiological factors (Pate et al., 2019; Raghuveer et al., 2020). Therefore, in Study III, adolescents were profiled based on their motor competence levels over time and the trajectories of MVPA and cardiorespiratory fitness examined in each of these profiles.

In Study III, latent profile analysis was used to identify distinct profiles of motor competence based on standardized scores of motor competence measurements collected over a period of five years. Three profiles were identified and labeled as low, moderate, and high, reflecting the different levels of motor competence in the study sample. Many previous studies have performed variable-driven grouping, including cut-points or percentiles, to identify different levels of motor competence (Hands, 2008; V. P. Lopes et al., 2011; Fransen et al., 2014; Haugen & Johansen, 2018; V. P. Lopes et al., 2021; Abrams et al., 2022). However, none of the previous clustering studies have applied data-driven profiling to identify groups of individuals with distinct configural profiles of personal attributes, such as motor skills (Woo et al., 2018). Summarizing the findings from previous studies indicates that children with low motor competence demonstrate lower levels of physical activity and cardiorespiratory fitness than peers with high motor competence (Hands, 2008; V. P. Lopes et al., 2011; Fransen et al., 2014; Haugen & Johansen, 2018; V. P. Lopes et al., 2021). However, evidence on the patterns of physical activity and cardiorespiratory fitness during adolescence has been lacking. This period is considered crucial as it may involve the presence of a motor proficiency barrier, as suggested by V. P. Lopes et al. (2021). This is important because fundamental movement patterns and basic skills, such as running, jumping, and throwing, should ideally be mastered prior to this stage of development (Clark & Metcalfe, 2002; Goodway et al., 2021).

The subsequent analysis revealed distinct trajectories of physical activity and cardiorespiratory fitness among individuals with low, moderate, and high motor competence profiles. Notably, the primary disparity lay in the significant variation in the initial levels from which these trajectories began. The initial levels of physical activity and cardiorespiratory fitness of each profile closely aligned with their respective labels: low, moderate, and high. This finding is consistent with previous findings (Hands, 2008; V. P. Lopes et al., 2011; Fransen et al., 2014; Haugen & Johansen, 2018; V. P. Lopes et al., 2021; Abrams et al., 2023). Thus, Study III provided some evidence for the possible existence of a motor proficiency barrier in early adolescence. The children in the low motor competence profile demonstrated the lowest initial levels of MVPA and cardiorespiratory fitness at age 11. Over the course of four years, from ages 11 to 15, all three profiles showed a consistent rate of change in cardiorespiratory fitness. This suggests that the initial differences remained significant and substantial throughout adolescence. Thus, the present data showed that adolescents characterized by poor motor competence and low fitness tend to maintain the same level, thereby harboring potential risks for unfavorable cardiometabolic conditions and weight development in the future (Garciá-Hermoso et al., 2020). The physical activity trajectories, on the other hand, differed between the high profile and the other two profiles. The low and moderate profiles did not exhibit significant changes over time, whereas the high profile declined significantly across adolescence. This finding conflicts with that reported by V. P. Lopes et al. (2011), who found that only the children who had a high initial level of motor competence maintained their physical activity. In contrast, the children with low and moderate initial levels showed a decline in physical activity between the ages of 6 and 10. Although a direct comparison between Study III and that by V. P. Lopes et al. (2011) is limited due to differences in methodology, it is possible to create a hypothetical scenario based on the available information. On average, physical activity tends to decline starting at age 7 (Lounassalo et al., 2019). According to V. P. Lopes et al. (2011), during this period, children with a high level of motor competence tend to maintain their physical activity levels until age 10, whereas children with low and moderate motor competence experience a decline in physical activity during the same period. Building on this, Study III suggests that starting from age 11, children with a high level of motor competence also experience a decline in physical activity until age 15. In contrast, those with low and moderate motor competence did not show significant changes but instead had reached a plateau below the recommended daily amount of 60 minutes. Adolescence is characterized by numerous physical, psychological, and social changes that can impact physical activity behavior, irrespective of the level of motor competence (Bélanger et al., 2011). These changes include dropout from organized sports (Kokko et al., 2019), identity formation, and the increasing significance of social support from peers (van Sluijs et al., 2021).

Study III showed that while cardiorespiratory fitness improved across all profiles, a similar trend was not found for physical activity. This may reflect maturation-related morphological changes that improve cardiorespiratory fitness, irrespective of physical activity (Raghuveer et al., 2020; Armstrong & Welsman, 2019a). However, in the high motor competence profile, a noteworthy association was observed: the greater the decline in physical activity, the less the improvement in cardiorespiratory fitness. A possible explanation for this could be a decrease in intense physical activity, which would reduce the exercise-induced enhancement of cardiorespiratory fitness. Previous studies have shown that children with higher motor competence also have higher levels of vigorous activity (Blomqvist et al., 2019), which is known to be a stronger correlate of cardiorespiratory fitness than moderate physical activity (Owens et al., 2017).

6.5 The role of sport participation on health-related fitness and weight status

As mentioned earlier, motor competence has been proposed as a driver of physical activity. However, Study III revealed that while adequate motor competence may enhance opportunities for successful participation in physical activities, such as organized sports (Vandorpe et al., 2012), it does not necessarily buffer against the decline in activity experienced during adolescence.

Nevertheless, it does appear to be associated with higher fitness. Furthermore, adolescents with high motor competence showed a positive association between cardiorespiratory fitness and MVPA, indicating that a larger decline in MVPA leads to fewer improvements in cardiorespiratory fitness. However, the significant variation across the sample in the development of MVPA and fitness raises the question of what other factors might explain the differences in fitness trajectories. Physical activity always takes place in a specific context, such as organized sports, which has particular significance for children and adolescents (Kokko et al., 2019). Previous research has consistently shown that children who participate in organized sports accumulate more vigorous physical activity and have better fitness levels than non-participating peers (Marques et al., 2016; Telford, Telford, Cochrane et al., 2016; Kokko et al., 2019; Smith et al., 2019). In Finland, approximately 60% of adolescents aged 9-15 participate in organized sports (Blomqvist et al., 2023). However, despite the initially high participation rates in organized sports during childhood, a significant proportion of participants drop out during adolescence (Crane & Temple, 2015; Kokko et al., 2019; Toivo et al., 2023). The role of organized sports in the development of health-related fitness and weight status among adolescents remains inadequately explored, especially on the issue of the immediate impact of dropout on health-related fitness and weight status during adolescence. Study IV revealed significant differences in the trajectories of cardiorespiratory and muscular fitness of adolescents who continued organized sport participation throughout adolescence, those who dropped out during adolescence, and those who had never participated in organized sports.

Adolescents who continued participating in organized sports throughout adolescence exhibited the highest initial levels of cardiorespiratory and muscular fitness as well as significant improvements over time. Adolescents who had never participated in organized sports or had dropped out before adolescence exhibited the lowest initial levels of fitness, but a similar rate of change compared to peers who continued their participation throughout adolescence. Thus, the initial differences in cardiorespiratory and muscular fitness between these adolescents remained significant, large, and equivalent over time, as also shown by Telford, Telford, Cochrane et al. (2016). The improvements in fitness during adolescence may in part be explained by the increase in fat-free mass that occurs during maturation (Armstrong & Welsman, 2019a; 2019b; Raghuveer et al., 2020; Malina et al., 2004). However, besides maturation, cardiorespiratory and muscular fitness can be improved through vigorous physical activity, which is often more common among adolescents who participate in organized sports (Kokko et al., 2019). While the results revealed no difference in rates of fitness improvement, a significant contrast was observed in baseline levels between adolescents who participated in organized sports and those who did not. This suggests that the divergence in cardiorespiratory and muscular fitness may begin earlier in childhood and/or that children with initially higher fitness levels are more likely to engage in organized sports, as proposed by Cairney and Veldhuizen (2016).

Interestingly, adolescents who dropped out of organized sports did not exhibit any improvements in cardiorespiratory fitness, and their gains in muscular fitness were significantly smaller those of their peers in the other two groups. Improvements in health-related fitness require physical activity of adequate intensity, frequency, and duration (Spiering et al., 2021). Nevertheless, it is important to recognize that these improvements in fitness are not permanent and may gradually diminish as the duration, frequency, or intensity of training is reduced (Spiering et al., 2021), which may be the case after dropping out of organized sports (Toivo et al., 2023). For example, Toivo et al. (2023) reported that most adolescents who participated in organized sports only accumulated higher levels of physical activity on training days when compared to non-participating peers. This raises the important question of whether additional physical activity and the accompanying fitness improvements obtained through organized sports are lost when individuals drop out, as suggested by the results of Study IV, indicating that when adolescents drop out from organized sports, the physical activity levels and fitness benefits previously obtained through such participation are not adequately replaced elsewhere. Continued participation in organized sports throughout adolescence serves as an important pathway for enhancing and sustaining high levels of health-related fitness, especially in our current sedentary-oriented era (LeBlanc et al., 2017). This is particularly important, as adolescents tend to become less active outside of organized activities (Toivo et al., 2023; Telford, Telford, Cochrane et al., 2016).

Studies on the association between participation in organized sports and weight status have yielded inconsistent findings (Nelson et al., 2011; Lee et al., 2016). Study IV shed light on this topic by showing that no significant differences occurred in the development of BMI between the three groups. However, it is noteworthy that initial BMI was higher in the non-participating group than in the other two groups, a finding which is consistent with some previous findings (Cairney & Veldhuizen, 2016; Drenowatz et al., 2019) but in conflict with others (Marques et al., 2016; Carlisle et al., 2019; Vella et al., 2013). The present finding suggests that children with a higher BMI may be less inclined to participate in organized sports (Cairney & Veldhuizen, 2016), possibly due to lower fitness levels (Rauner et al., 2013) and increased body consciousness (Zabinski et al., 2003). Conversely, it may also suggest that participating in organized sports can promote a healthier weight status. However, the longitudinal findings of Study IV indicate that this is not the case, as the three groups showed no differences in BMI development. In other words, dropping out of organized sports did not appear to have a significant influence on BMI development during adolescence. However, additional research with an extended follow-up period and more accurate body composition measurements is necessary, as it is possible for changes in body composition, such as a reduction in muscle mass and an increase in fat mass, to occur while BMI remains unchanged (Cruz et al., 2011).

6.6 Limitations

While there are several strengths in the studies comprising this dissertation, such as the longitudinal design, large number of participants, device-measured physical activity, and use of person-oriented statistical approaches, they also have their limitations. Firstly, causality cannot be established with the longitudinal analyses utilized in this observational research design. In Studies I, II, and III, a common limitation was the assessment of physical activity in only a subsample of participants. Notably, differences were observed between those who wore actigraphs (subsample) and those who did not. The participants in the subsample demonstrated better motor competence and fitness over the years (see Appendix 3). The number of participants in the subsample who were willing to wear the accelerometer decreased each year. However, no significant between-group difference in MVPA was found in any earlier year between those who wore actigraphs in the final year and those who chose not to (see Appendix 3). Finally, physical activity was measured based on a three-day snapshot and did not include activities in water. Therefore, caution the findings related to MVPA must be interpreted with caution. Furthermore, motor competence was assessed solely through product-oriented measurements, which are more closely linked to health-related fitness and BMI. Incorporating both product- and process-oriented measures would have offered a more comprehensive insight into the understanding of motor competence and its associations with the other variables (Logan et al., 2017). In Studies I, II, and IV, BMI was used to assess the participants' weight status. Although BMI is a widely used measure for tracking changes in adiposity, it may be inaccurate in children and adolescents due to maturational growth and its inability to differentiate between muscle mass and fat (Nuttall, 2015). The absence of measurements for maturation status in Studies I and II is a significant limitation. Maturation, which involves various physiological changes (Malina et al., 2004), can potentially impact the variables used in a study of this kind, including motor competence, cardiorespiratory fitness, and BMI. Finally, it is important to note that the measure of perceived motor competence used in this study is part of the broader concept of physical self-perception. Therefore, the findings may not be directly comparable with those of studies that have employed a questionnaire on perceived motor competence in conjunction with motor competence measures, such as the Pictorial Scale of Perceived Movement Skill Competence (PMSC). These limitations should be considered when interpreting the results and their practical implications.

7 CONCLUSIONS, PRACTICAL IMPLICATIONS AND FUTURE DIRECTIONS

7.1 Conclusions

The findings of Studies I–IV can be summarized as follows:

I) Adolescents varied significantly in the development of their actual and perceived motor competence, cardiorespiratory fitness, physical activity, and BMI from 11 to 14 years of age. However, on average, they showed an increase in BMI, cardiorespiratory fitness, and motor competence, as well as a decline in MVPA and perceived motor competence. Furthermore, the adolescents who demonstrated a greater increase in BMI showed a larger decline in MVPA and a lower level of improvement in cardiorespiratory fitness. These findings suggest that some adolescents may become trapped in a self-perpetuating cycle of obesity, physical inactivity, and poor fitness. This highlights the importance of targeted interventions to disrupt this cycle and encourage healthier behaviors among this age group.

II) Three distinct profiles of actual and perceived motor competence, cardiorespiratory fitness, physical activity, and BMI were identified. One of these profiles exhibited a positive cycle of engagement, characterized by higher levels of actual and perceived motor competence, cardiorespiratory fitness, and physical activity. The other two profiles exhibited a negative cycle of disengagement, with lower scores in all four variables. Notably, the profile associated with overweight, and obesity was characterized by a negative spiral of disengagement. Importantly, these profiles remained relatively stable from early to middle adolescence. This suggests that if children exhibit a negative cycle at age 11, it is likely to remain present at age 14. This underscores the significance of early interventions, as addressing these issues sooner rather than later is crucial. Without any targeted actions in childhood, these characteristics may persist into adulthood. Adolescents with low levels of physical activity and poor motor competence and fitness may be at risk for developing overweight or obesity.

III) Three distinct profiles of motor competence were identified over a four-year period during adolescence: low, moderate, and high. The baseline levels of cardiorespiratory fitness and MVPA were consistent with the names given to these profiles. The adolescents in the low and moderate motor competence profiles did not show any changes in MVPA over time. This means that their MVPA levels remained below the recommended 60 minutes per day throughout the four-year period. In contrast, the adolescents in the high motor competence profile initially exceeded 60 minutes of MVPA per day but showed a significant decrease in MVPA thereafter. Despite these differences in MVPA, all three profiles exhibited a similar increase in cardiorespiratory fitness. This indicates that the baseline variation in cardiorespiratory fitness levels remained significant and consistent throughout adolescence. The findings suggest that addressing physical inactivity during adolescence requires approaches that take into consideration individuals' different levels of motor competence. Fostering early motor competence in childhood through customized interventions may, in turn, improve physical activity and cardiorespiratory fitness levels in adolescence.

IV) Although many children initially participated in organized sports, many also dropped out during adolescence. The adolescents who continued to participate in organized sports showed the highest initial levels of cardiorespiratory and muscular fitness, and significant improvements in these variables over time. Conversely, the adolescents who dropped out of organized sports during adolescence showed no changes in cardiorespiratory fitness and smaller improvements in muscular fitness. These findings suggest that dropping out of organized sports leads fitness improvement to plateau. This indicates that engagement in other types of activities does not adequately compensate for the physical activity previously generated by engagement in organized sports. Therefore, it is advisable to provide and promote a range of physical activity options in sport clubs and after-school programs to improve fitness among adolescents, including those who may prefer non-competitive activities.

7.2 Practical implications

The findings of Study I primarily highlight the diversity in the development of health-related factors during adolescence and emphasize the importance of the associations between these variables, with particular emphasis on the critical role of physical activity and fitness in weight development. However, they also raise the question of whether weight gain could contribute to a decline in physical activity and cardiorespiratory fitness. Promoting physical activity among children and adolescents, especially those who are overweight or obese, is extremely important. Schools can play a vital role in implementing these initiatives. Research by Ip et al. (2017) has shown that establishing school environments that promote physical activity is linked to a decreased risk of obesity. Other research has demonstrated the effectiveness of school-based interventions that integrate physical activity and nutrition in preventing obesity (Bleich et al., 2018). Furthermore, the study by Simon et al. (2008) highlighted the potential of multilevel physical activity interventions in preventing weight gain among middle-school children whose weight is normal. It is equally important to ensure that physical activity opportunities are accessible and safe for everyone, regardless of their weight status or fitness level. This can be achieved by combating weight stigma through practitioner education (Pont et al., 2017; Pearl et al., 2021) and by involving adolescents in planning strategies to promote physical activity (James et al., 2018; van Sluijs et al., 2021). The finding of Study II, along with prior research by Webster et al. (2021), has indicated that adolescents with overweight and obesity may have lower levels of locomotor skills and aerobic performance compared to peers. This can have an impact on their ability and motivation to participate in physical activities. Therefore, recognizing the diversity within the adolescent population and designing targeted interventions to promote physical activity and prevent obesity are essential. These interventions should be inclusive and consider the specific needs and capabilities of individuals, ensuring that all adolescents have opportunities to lead active and healthy lives.

The findings from Studies II and III strongly emphasize the importance of personalized approaches in promoting physical activity and fostering healthy lifestyles among adolescents. These studies revealed that adolescents exhibit varying levels of abilities related to physical activities, including motor competence and health-related fitness. Consequently, some adolescents may find themselves in a positive spiral of engagement, while others may experience a negative spiral of disengagement, as outlined in the conceptual model by Stodden et al. (2008). To effectively address this diversity and promote physical activity, it is essential to identify individuals' characteristics as early as possible and plan tailored actions. This approach aligns with the results of a recent quasi-experimental intervention by Huhtiniemi et al. (2023), which suggested that targeting interventions towards groups of elementary schoolchildren with particularly low motor competence and health-related fitness may lead to significant improvements in these variables. Overall, promoting motor competence in childhood through physical education in schools, sports club settings, daycare centers, and homes could be an effective strategy to ensure that all children have the necessary skills to engage in physical activity in the future. This requires educating and encouraging coaches, teachers, and families to support the development of children's motor skills and promote a variety of physical activities. For example, high-quality physical education classes contribute not only to immediate health and well-being but also to the long-term development of motor competence. Furthermore, comprehensive interventions should involve families, friends, and sports clubs while also promoting changes in the built environment (van Sluijs et al., 2021). This can create a sustained cycle of engagement with physical activity and promote healthy living for children and adolescents.

It is essential to recognize that the decline in physical activity is not limited solely to individuals with lower motor competence and fitness. As highlighted in Study III, even highly active and motor-competent adolescents may exhibit a decline in physical activity (Lounassalo et al., 2019). Therefore, interventions that encompass multiple components and consider both individual characteristics and contextual factors, such as the uniqueness of the school environment, may prove advantageous (Jago et al., 2023). Although school-based interventions have often shown limited success in changing physical activity behavior, schools remain an important avenue as they reach most adolescents (van Sluijs et al., 2021; Jago et al., 2023). Some school-based interventions, such as the study conducted by Sutherland et al. (2019), have yielded promising results. Their intervention strategy included multiple approaches to promote physical activity, such as individualized student physical activity plans and after-school community sport and fitness programs (Sutherland et al., 2019). Interestingly, both strategies support the evidence presented in this dissertation, suggesting the potential effectiveness of these approaches in promoting physical activity among adolescents.

The findings of Study IV highlight the significance of organized sports participation on health-related fitness in adolescence, indicating that sports clubs can serve as valuable institutions for promoting adolescents' physical activity and health (García-Hermoso et al., 2020) in our current sedentary-oriented environment (LeBlanc et al., 2017; Ng & Popkin, 2012). This points to a potential need to reevaluate the primary objectives of organized sports. Perhaps, in addition to focusing on athletic development during adolescence, organized sports clubs could expand their agendas to include non-competitive options and various forms of group exercise for adolescents, as suggested by Logan et al. (2019). Low-cost and easily accessible organized physical activities could also be a way of promoting physical activity among adolescents. Such alternatives could be offered through various channels, including sports clubs, schools, communities, and healthcare authorities, making it easier for adolescents to engage in regular physical activity.

7.3 Future research

Future studies could evaluate several key areas to enhance our understanding of the complex relationships between physical activity, motor competence, perceived sport competence, fitness, and weight status during adolescence. One avenue of inquiry could be to establish the causal connections between these variables. Specifically, researchers could explore whether weight gain serves as a catalyst for the decline in physical activity or vice versa and clarify the mechanisms underlying these dynamics. For example, it would be useful to assess the accessibility of physical activity opportunities for adolescents across a range of weight statuses, levels of motor competence, and fitness levels. Identifying potential disparities in access to and participation in physical activities and developing strategies to address these would be an important goal for future research.

To optimize interventions, future studies could adopt a three-step approach. First, they could employ profiling techniques to categorize adolescents based on characteristics such as motor competence, perceived sport competence, fitness, physical activity, weight status, or membership of sport clubs. Subsequently, specific interventions could be designed and piloted in focus groups to investigate the effectiveness of the method. Finally, if proven effective, it could be expanded and implemented in schools, communities, or sports club settings to encourage physical activity and prevent obesity among adolescents. Moreover, during the scale-up phase, further studies on the effectiveness of the method could be conducted. The potential impact of early childhood interventions, especially those focused on promoting motor competence in environments such as school physical education and daycare centers also merits further investigation. Such initiatives may serve as a foundational steppingstone towards a lifelong commitment to physical activity. The continuity of physical activity behaviors beyond adolescence, with a focus on investigating how interventions can support individuals in maintaining active and healthy lifestyles into adulthood, should also be a topic of interest. In relation to personalized approaches, the integration of person-oriented research methods and Artificial Intelligence (AI) presents a promising avenue for future research. AI technologies could significantly improve the design and implementation of personalized strategies to promote physical activity and encourage healthy lifestyles among adolescents. Thus, to fully capitalize on its significant potential, AI should be integrated into physical activity research.

Furthermore, future research could explore the idea, mentioned above, of expanding the athletic-centered objectives of organized sports clubs to incorporate non-competitive alternatives and diverse forms of group exercise for adolescents. Moreover, these activities could be delivered through various channels, including sports clubs, schools, communities, and healthcare authorities, thereby making regular physical activity more accessible for adolescents. Overall, it would be essential to conduct a comprehensive examination of societal influences that can promote adolescent physical activity and prevent obesity. Exploring policy-level changes that can promote a culture of physical activity and health should also be included in future research endeavors.

YHTEENVETO (SUMMARY IN FINNISH)

Fyysisen aktiivisuuden, motorisen pätevyyden, koetun motorisen pätevyyden, fyysisen kunnon ja painon kehitys sekä yhteydet 11–15-vuotiailla: 4 vuoden seurantatutkimus

Lihavuus ja fyysinen passiivisuus muodostavat merkittävän maailmanlaajuisen kansanterveydellisen ongelman. Molemmat ovat merkittäviä itsenäisiä riskitekijöitä useille elintapasairauksille, kuten sydän- ja verisuonisairauksille sekä aineenvaihdunnan sairauksille, kuten tyypin 2 diabetekselle. On arvioitu, että maailmanlaajuisesti fyysisen passiivisuuden kustannukset ovat yli 50 miljardia dollaria, josta yli puolet kattaa julkinen sektori. Samanaikaisesti kun fyysinen aktiivisuus on vähentynyt, ylipaino ja lihavuus ovat edellisten vuosikymmenten aikana länsimaissa yleistyneet. Näiden huolestuttavien trendien taustalla näyttäisi olevan länsimaiden muuttunut elintarvikejärjestelmä sekä elinympäristö, jossa teknologian ja asumisympäristöjen kehitys ovat vähentäneet liikkumisen tarvetta. Nämä muutokset vaikuttavat merkittävästi aikuisiin, mutta erityisesti lapsiin. Kansainvälisten fyysisen aktiivisuuden suositusten mukaan lasten ja nuorten tulisi liikkua päivittäin vähintään tunti reippaalla tai rasittavalla intensiteetillä. Tällä hetkellä suositusten mukaan liikkuvat lapset ja nuoret ovat kuitenkin selvä vähemmistö niin kansainvälisesti kuin Suomessakin. Lisäksi on osoitettu, että fyysinen aktiivisuus vähenee entisestään lapsen vanhetessa ja esimerkiksi Suomessa 15-vuotiaista suositusten mukaan liikkuu enää noin joka kymmenes.

Lapsuudessa vähän liikkuvat yksilöt jatkavat todennäköisesti vähäisempää liikkumista myös aikuisina. Samoin on osoitettu, että lapsuuden lihavuus on merkittävä ennustaja lihavuudelle aikuisiässä. Fyysinen aktiivisuus muodostuu osaksi yksilön elämäntapaa jo varhaisessa elämänvaiheessa. Lapsuudessa opitut liikuntataidot eli motoriset perustaidot (välineenkäsittelytaidot, liikkumistaidot ja tasapainotaidot) ovat perusta myöhemmälle liikkumiselle. Motoriset perustaidot toimivat rakennuspalikkoina erilaisille liikuntamuodoille. Varhaislapsuudessa, kun kognitiiviset taidot vasta kehittyvät, lapsi ei ole vielä kykenevä realistisesti arvioimaan omia motorisia taitojaan, vaan niiden tasosta riippumatta kokee yleensä olevansa hyvä. Lasten motorisen pätevyyden kehittyminen riippuu suuresti ympäristötekijöistä, sillä motoriset taidot eivät kehity automaattisesti lapsen kasvaessa, vaan erilaisten kokemusten, toistojen ja harjoittelun seurauksena. Oppiakseen on harjoiteltava. Motoristen taitojen oppiminen jättää pysyvän jäljen hermo-lihasjärjestelmään, jolloin opitut taidot on helpompi palauttaa mieleen pidemmänkin ajanjakson jälkeen. Kun lapsi varttuu, hän alkaa ymmärtämään, millainen hän on suhteessa muihin. Tässä vaiheessa niille lapsille, joilla on heikompi motorinen pätevyys, kehittyy helpommin myös heikompi koettu pätevyys suhteessa liikuntaan. Koetulla pätevyydellä taas on suuri vaikutus siihen, mitä motivoituu tekemään. Lapsien, joilla on heikko motorinen ja koettu pätevyys, ajatellaan ajautuvan negatiiviseen kierteeseen, jossa myös fyysinen aktiivisuus on vähäistä ja seurauksena myös fyysinen kunto jäädä heikoksi. Lisäksi on esitetty, että näillä lapsilla olisi suurempi ylipainon kehittymisen riski vähäisemmän liikunnan vuoksi, mikä puolestaan vaikuttaisi negatiivisesti kaikkiin edellä mainittuihin ominaisuuksiin. Päinvastoin niiden lasten, joilla on hyvät motoriset taidot, korkea koettu pätevyys ja hyvä kunto ajatellaan ohjautuvan positiiviseen kierteeseen, jolloin he olisivat myös fyysisesti aktiivisempia ja siten pienemmässä riskissä ylipainon kehittymiselle. Nämä edellä esitetyt kehitykselliset yhteydet ovat kuitenkin suurimmilta osin vain teoreettisia näkemyksiä, eikä esimerkiksi pitkittäisyhteyttä motoristen taitojen ja fyysisen aktiivisuuden välillä ole pystytty luotettavasti osoittamaan. Useita näistä yhteyksistä on tutkittu vain yhdessä aikapisteessä eli poikkileikkaus-asetelmalla. On kuitenkin pystytty osoittamaan, että lapset, joilla on korkeampi motorinen ja koettu pätevyys ovat myös fyysisesti aktiivisempia, paremmassa fyysisessä kunnossa ja todennäköisemmin normaalipainoisia. Kuitenkin näiden ominaisuuksien kehityksellisistä yhteyksistä murrosiässä on hyvin vähäisesti tietoa. Tämän neljästä tieteellisestä osajulkaisusta ja niiden yhteenvedosta koostuvan väitöskirjatutkimuksen tarkoituksena oli selvittää, miten nämä ominaisuudet eli motorinen pätevyys, koettu pätevyys, fyysinen kunto, fyysinen aktiivisuus ja painoindeksi kehittyvät nuorilla murrosiän aikana ja minkälaisia yhteyksiä näiden ominaisuuksien kehityksillä on toisiinsa. Lisäksi tässä väitöskirjatutkimuksessa tarkasteltiin, minkälainen vaikutus urheiluseura-harrastamisella on näiden ominaisuuksien kehittymiselle.

Tämä väitöskirjatutkimus oli osa viisivuotista seurantatutkimusta, joka alkoi ensimmäisellä aineistonkeruulla vuonna 2017. Tuolloin tutkittavat olivat viidennellä luokalla, eli noin 11-vuotiaita. Seuraavien neljän vuoden ajan, vuosina 2018–2021, tutkittaville suoritettiin samat mittaukset. Tutkimukseen osallistui yli tuhat tutkittavaa eri puolilta Suomea. Mittaukset toteutettiin syksyisin ja ne kattoivat monipuolisesti erilaisia fyysiseen aktiivisuuteen liittyviä olevia osa-alueita. Tutkittavilta mitattiin paino ja pituus, joista laskettiin painoindeksi. Motorisia taitoja mitattiin suorittamalla pallonheitto-kiinniotto-yhdistelmä, vauhditon 5-loikka sekä sivuttaishyppely puomin yli -mittaus. Fyysistä kuntoa mitattiin 20-metrin viivajuoksutestillä sekä etunoja-punnerrustestillä. Lisäksi tutkimuksessa kartoitettiin koettua pätevyyttä ja urheiluseuraharrastusta kyselyllä, kun taas fyysistä aktiivisuutta mitattiin kiihtyvyysantureilla. Väitöskirjatutkimuksessa käytettiin edistyneitä tilastollisia menetelmiä, kuten kasvukäyräanalyysia (osajulkaisut I, III, IV), profiilianalyysiä (osajulkaisut II, III) ja siirtymäanalyysiä (osajulkaisu II). Täsmennetyt tutkimuksen tavoitteet olivat seuraavanlaiset:

I) Tutkia kehityksellisiä yhteyksiä motorisen pätevyyden, koetun pätevyyden, kestävyyskunnon, fyysisen aktiivisuuden ja paino-indeksin välillä murrosiässä.

II) Tunnistaa erilaisia ryhmiä nuorten motorisen pätevyyden, koetun pätevyyden, kestävyyskunnon, fyysisen aktiivisuuden ja paino-indeksin perusteella sekä tarkastella näiden ryhmien pysyvyyttä murrosiässä.

III) Tunnistaa erilaisia ryhmiä nuorten motoriseen pätevyyteen perustuen ja tutkia kestävyyskunnon sekä fyysisen aktiivisuuden kehitystä näissä ryhmissä.

IV) Tutkia fyysisen kunnon ja painoindeksin kehityseroja kolmen ryhmän välillä: 1) niiden, jotka jatkoivat tai aloittivat organisoituneen urheiluharrastuksen murrosiässä, 2) niiden, jotka lopettivat harrastuksen, ja 3) niiden, jotka eivät koskaan osallistuneet tai lopettivat ennen murrosikää.

Väitöskirjatutkimuksen (osajulkaisu I) tulokset osoittavat, että murrosiässä painoindeksi, motorinen pätevyys ja fyysinen kunto kasvavat, kun taas koettu pätevyys ja fyysinen aktiivisuus laskevat. Näissä kehityksissä havaittiin kuitenkin merkittäviä eroja yksilöiden välillä. Yksitoistavuotiaista lapsista ne, joilla oli paremmat motoriset taidot, olivat myös fyysisesti aktiivisempia ja parempikuntoisia. Pitkittäisanalyysi paljasti, että voimakkaampi painoindeksin nousu oli yhteydessä voimakkaampaan fyysisen aktiivisuuden laskuun ja vähäisempään kestävyyskunnon kehittymiseen nuoruudessa. Motoristen taitojen ja fyysisen aktiivisuuden välillä ei havaittu kehityksellistä yhteyttä, mutta kestävyyskunnon ja motoristen taitojen kehityksien välillä oli positiivinen yhteys.

Kun nuoria profiloitiin perustuen motoriseen ja koettuun pätevyyteen, kestävyyskuntoon, fyysiseen aktiivisuuteen ja painoindeksiin (osajulkaisu II), havaittiin, että on löydettävissä kolme erilaista ryhmää. Ensimmäiseen ryhmään kuului noin 40 % nuorista, missä heitä yhdisti hyvät motoriset taidot, korkea koettu pätevyys, hyvä kestävyyskunto, korkea fyysinen aktiivisuus sekä normaalipainoisuus. Toisessa ja kolmannessa ryhmässä nuoret olivat enemmän samankaltaisia keskenään. Näissä kahdessa ryhmässä nuoret liikkuivat alle suosituksien, ja heillä oli ensimmäiseen ryhmään verrattuna heikommat motoriset taidot, koettu pätevyys sekä kestävyyskunto. Näiden kahden ryhmän erona oli se, että toisessa (noin 40 %) nuorilla oli pääsääntöisesti normaalipaino ja toisessa (noin 20 %) pääsääntöisesti ylipaino tai lihavuus. Siinä ryhmässä, jossa lapsilla oli pääsääntöisesti ylipainoa tai lihavuutta, heillä oli myös kahteen muuhun ryhmään verrattuna heikommat tulokset painosta riippuvista mittauksista, kuten 5-loikasta, sivuttaishyppelystä puomin ylitse ja 20-metrin viivajuoksusta.

Kun nuoria profiloitiin perustuen pelkästään motorisiin taitoihin viiden vuoden aikana (osajulkaisu III), löydettiin kolme toisistaan eriävää ryhmää. Nimellisesti ja kuvaavasti nämä olivat korkean motorisen pätevyyden ryhmä (noin 30 %), keskivertaisen motorisen pätevyyden ryhmä (noin 50 %) ja heikon motorisen pätevyyden ryhmä (20 %). Kasvukäyräanalyysillä havaittiin, että 11-vuotiaana eli ensimmäisessä mittauspisteessä näillä kolmella eri motoristen taitojen ryhmällä oli merkittävästi erilainen kestävyyskunnon sekä fyysisen aktiivisuuden taso. Korkean motorisen pätevyyden ryhmällä oli korkeimmat tasot, kun taas alhaisen motorisen pätevyyden ryhmällä heikoimmat. Pitkittäisanalyysi paljasti, että kaikissa profiileissa kestävyyskunto kasvoi samalla tavalla neljän vuoden aikana, joten alkuperäiset erot säilyivät merkittävinä ja suhteellisen suurina. Alhaisen ja keskivertaisen motorisen pätevyyden ryhmillä fyysisen aktiivisuuden taso ei muuttunut neljän vuoden aikana, vaan säilyi alle suositusten. Korkean motorisen pätevyyden ryhmällä fyysinen aktiivisuus laski merkittävästi neljän vuoden aikana päätyen loppujen lopuksi lähelle samaa tasoa kahden muun ryhmän kanssa.

Lopuksi selvitettiin, miten urheiluseuraharrastaminen on yhteydessä kestävyyskuntoon, lihaskuntoon ja painoindeksiin murrosiässä (osajulkaisu IV). Tulokset osoittivat, että niillä nuorilla, jotka aloittivat tai jatkoivat organisoitua urheiluseuraharrastamista läpi murrosiän (Jatkajat), oli korkeimmat tulokset kestävyys- ja lihaskuntomittauksissa 11-vuotiaina. Toiseksi korkeimmat tulokset oli niillä nuorilla, jotka osallistuvat organisoituun urheiluseuraharrastamiseen 11-vuotiaina, mutta lopettivat murrosiän aikana (Lopettajat) ja heikoimmat niillä, jotka eivät olleet koskaan osallistuneet organisoituun urheiluseuraharrastamiseen tai olivat lopettaneet ennen ikävuotta 11 (Ei-harrastavat). Ei-harrastavien ryhmällä oli myös 11-vuotiaina merkittävästi korkeampi painoindeksi verrattuna kahteen muuhun ryhmään. Pitkittäisanalyysi osoitti, että kestävyys- ja lihaskunto kasvoivat samalla lailla Jatkavilla ja Ei-harrastaneilla nuorilla ikävuosien 11 ja 15 välillä, eli erot pysyivät merkittävinä ja suhteellisen suurina läpi nuoruuden. Lopettajilla taas kestävyyskunto ei kehittynyt ollenkaan neljän vuoden aikana ja lihaskunto merkittävästi vähemmän kuin kahdella muulla ryhmällä. Lopputuloksena viimeisessä mittauspisteessä 2021 Lopettajilla ja Ei-harrastavilla ei ollut kestävyys- ja lihaskunnon välillä enää merkittäviä eroja. Painoindeksin kehityksessä ei ollut ryhmien välillä merkittävää eroa.

Tämän väitöskirjatutkimuksen tulokset korostavat vaihtelua nuorten välillä. Jokainen nuori on erilainen ja kehittyy yksilöllisesti, mikä tarkoittaa, että liikunnan ja painonhallinnan edistämiseksi yksi ratkaisu ei sovi kaikille. Osatutkimuksen I tulokset painottavat fyysisen aktiivisuuden ja fyysinen kunnon yhteyttä painoindeksin kehittymiseen. Vaikka usein oletetaan, että vähenevä fyysinen aktiivisuus johtaa painonnousuun, tämä tutkimustulos herättää myös kysymyksen siitä, voiko painonnousulla olla negatiivinen vaikutus fyysiseen aktiivisuuteen. Toisen osatutkimuksen mukaan nuorilla, joilla esiintyy ylipainoa tai lihavuutta, on heikompi motorinen pätevyys ja fyysinen kunto verrattuna normaalipainoisiin ikätovereihinsa. Tämä voi vaikuttaa heidän kykyihinsä ja motivaatioonsa osallistua fyysisiin aktiviteetteihin. Kohdennettuja toimia fyysisen aktiivisuuden edistämiseksi ja lihavuuden ehkäisemiseksi suunnitellessa on olennaista ottaa huomioon nämä yksilöiden erilaiset ominaisuudet. Osatutkimukset II ja III yhtä lailla korostavat yksilöllisten lähestymistapojen merkitystä liikunnan ja painonhallinnan edistämisessä. Tulokset osoittivat, että nuoret eroavat huomattavasti toisistaan niin motorisen pätevyyden, koetun pätevyyden, fyysisen aktiivisuuden kuin fyysisen kunnonkin suhteen. Näiden tutkimuksien tulokset tukivat alussa esitettyjä käsityksiä negatiivisesta ja positiivisesta kierteestä. Negatiivisen kierteen ehkäisemiseksi olisi olennaista tunnistaa yksilöiden ominaisuudet mahdollisimman varhaisessa vaiheessa ja suunnitella niiden pohjilta räätälöityjä toimenpiteitä. Yleisesti ottaen motorisen pätevyyden edistäminen lapsuudessa päiväkotien, koulujen, urheiluseurojen ja kotien kautta on tehokas strategia varmistamaan, että kaikilla lapsilla olisi tarvittavat rakennuspalikat fyysisesti aktiivista elämäntapaa varten. Esimerkiksi laadukas liikuntakasvatus tarjoaa arvokkaita etuja, edistäen paitsi välitöntä terveyttä ja hyvinvointia, myös pitkäaikaista motorisen pätevyyden kehittymistä. Kuitenkaan pelkkä motorinen pätevyys ei näytä riittävän fyysisen aktiivisuuden ylläpitämiseksi, saati sen edistämiseksi nuoruudessa. Tarvitsemme sekä yksilöihin keskittyvää lähestymistapaa, mutta myös toimenpiteitä, jotka kohdentuisivat elinympäristöömme, tehden siitä fyysiseen aktiivisuuteen kannustavan. Osatutkimus IV korostaa organisoitujen urheiluharrastusten merkitystä fyysisen kunnon kehittymisessä murrosiässä. Urheiluseurat voivatkin toimia arvokkaana väylänä nuorten fyysisen aktiivisuuden ja terveyden edistämiseksi. Urheiluseurat voisivat enenevissä määrin laajentaa tarjontaansa sisältämään tavoitteellisen harrastamisen lisäksi myös monipuolisesti muita vaihtoehtoja. Edulliset ja helposti saavutettavat organisoidut fyysiset aktiviteetit voisivat toimia tehokkaina keinoina edistää nuorten fyysistä aktiivisuutta ja kuntoa. Näitä aktiviteetteja voitaisiin tarjota eri kanavien kautta, mukaan lukien urheiluseurat, koulut, yhteisöt ja kunnat, mikä tekisi ohjattuun toimintaan osallistumisesta nuorille käytännöllisemmän vaihtoehdon.

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APPENDIX 1. **The Physical Self-Perception Profile, Sport Competence**

The Finnish version of the Physical Self-Perception Profile, Sport Competence Dimension (Fox & Corbin, 1989).

Olen huono urheilussa	1	2	3	4	5	Olen hyvä urheilussa
Kuulun taidoiltani heikoimpiin liikunnassa	1	2	3	4	5	Olen mielestäni parhaimmasta päästä liikunnassa
En luota itseeni urheilutilanteissa	1	2	3	4	5	Olen itsevarma urheilutilanteissa
En kuulu niihin oppilaisiin, joita valitaan urheilutehtäviin (joukkue, kilpailut, mallisuoritukset)	1	2	3	4	5	Olen kyvykkäimpien joukossa valittaessa oppilaita urheilutehtäviin (joukkue, kilpailut, mallisuoritukset)
Vetäydyn taka-alalle, kun tarjoutuu mahdollisuus päästä suorittamaan urheilutehtäviä (joukkue, kilpailut, mallisuoritukset)	1	2	3	4	5	Olen ensimmäisten joukossa, kun tarjoutuu mahdollisuus päästä suorittamaan urheilutehtäviä (joukkue, kilpailut, mallisuoritukset)

The English version of the Physical Self-Perception Profile, Sport Competence Dimension (Fox & Corbin, 1989).

I am good at sport	1	2	3	4	5	I am not good at sport
I am among the best when it comes to athletic ability	1	2	3	4	5	I am not among the best when it comes to athletic ability
I feel confident when participating in sport activities	1	2	3	4	5	I do not feel confident when participating in sport activities
I am not among the best when it comes to joining when it comes to joining sport activities (teams, games etc.)	1	2	3	4	5	I am among the best when it comes to joining when it comes to joining sport activities (teams, games etc.)
I draw back when it comes in sport activities to join in sport activities (teams, games, etc.)	1	2	3	4	5	I am among the first to join when it comes in sport activities to join in sport activities (teams, games, etc.)

APPENDIX 2. **Information to parents and consent for participation in the study**

Move! järjestelmän yhteys oppilaiden fyysiseen toimintakykyyn fyysiseen aktiivisuuteen ja liikuntamotivaatioon koululiikunnassa

TIEDOTE VANHEMMILLE JA SUOSTUMUS TUTKIMUKSEEN OSALLISTUMISESTA

Tutkijoiden yhteystiedot

Vastuullinen tutkija:

Timo Jaakkola. LitT, dosentti, Jyväskylän yliopisto, [redacted]

Muut tutkijat:

Kasper Mäkelä, LitT, Jyväskylän yliopisto, [redacted]
Mikko Huhtiniemi, LitM, Jyväskylän yliopisto, [redacted]
Iiris Kolunsarka, tutkimusavustaja, Jyväskylän yliopisto, [redacted]

Yhteistyökumppanit:

Professori Jarmo Liukkonen (JY)
Dosentti Arja Sääkslahti (JY)
Professori Martin Hagger (JY)
Professori Heikki Kyröläinen (JY)
Tutkimusjohtaja Tuija Tammelin (LIKES)
Professori Stuart Biddle (Victorian yliopisto, Melbourne, Australia)
Professori Keith Davids (Sheffield Hallamin yliopisto, Sheffield, Englanti)
Apulaisprofessori Sami Yli-Piipari (Georgian yliopisto, Athens, Yhdysvallat)
Apulaisprofessori Anthony Watt (Victorian yliopisto, Melbourne, Australia)

Tutkimuksen taustatiedot

Tutkimus toteutetaan Jyväskylän yliopistossa liikuntatieteellisessä tiedekunnassa. Tutkimusaineistoa kerätään maantieteellisesti eri paikoissa sijaitsevilta suomalaisilta kouluilta. Tutkimuksen johtajana toimii LitT, dosentti Timo Jaakkola. Väitöskirjan jälkeistä tutkimustyötä (post doc) projektissa tekee LitT Kasper Mäkelä. Väitöskirjoja projektin aineistoista valmistelevat LitM Mikko Huhtiniemi sekä LitM Sanni Seppälä. Lisäksi projektista syntyy pro gradu –tutkielmia, joita edellä mainitut henkilöt ohjaavat. Tutkimuksen aineisto kerätään vuosina 2017–2021. Tämän tutkimusprojektin rahoittaja on Opetus- ja kulttuuriministeriö.

Tutkimuksen tarkoitus, tavoite ja merkitys

Tutkimuksen tarkoituksena on analysoida kaikki suomalaiset 5.- ja 8.-luokkalaiset oppilaat tavoittavan Move! –fyysisen toimintakyvyn seurantajärjestelmän tehokkuutta. Projektissa tutkitaan myös oppilaiden, kouluterveydenhuollon, opettajien sekä oppilaiden vanhempien kokemuksia Move! -järjestelmästä. Lisäksi tutkimusprojektissa seurataan koululaisten motorisia taitoja, fyysistä kuntoa, ja aktiivisuutta, koulumenestystä sekä motivaatiokokemuksia fyysistä aktiivisuutta ja koululiikuntaa kohtaan viidenneltä luokalta yhdeksännelle luokalle.

Tutkimuksen tuottama tieto on merkittävää erityisesti uuden Move! –järjestelmän kehittämisen kannalta. Samoin tutkimus tuottaa tärkeää tietoa erityisesti oppilaiden fyysisestä toimintakyvystä, fyysisestä aktiivisuudesta ja liikuntamotivaatiosta, ja niiden kehittymisestä lapsuudesta nuoruuteen.

Tutkimusaineiston käyttötarkoitus, käsittely ja säilyttäminen

Tutkimusaineistoa käytetään tutkimuksellisiin tarkoituksiin. Siitä julkaistaan opinnäytetöitä, kansainvälisiä tutkimusartikkeleita sekä yleistajuisia artikkeleita ammatillisiin sekä yleisiin lehtiin. Tutkimuksen tuottamaa tietoa käytetään myös liikunnan- ja terveystiedonopettajakoulutuksen kehittämiseen.

Tutkittavien tunnistetietoja ei tallenneta tutkimusaineistoon. Jokaiselle tutkittavalle annetaan oma tutkimusaineistoon tallennettava koodi, jonka avulla eri ajankohtina kerätyt aineistot voidaan yhdistää toisiinsa. Tutkittavien nimet sisältävä koodiavain säilytetään yliopiston salasanojen takana olevalla serverillä ja hävitetään kun eri tutkimustehtäviin liittyvät viimeiset mittaukset on suoritettu ja tallennettu tutkimusaineistoon. Sähköistä tutkimusaineistoa säilytetään salasanan takana olevalla yliopiston serverillä. Tutkittavilta kerätyt kyselylomakkeet säilytetään yliopiston tiloissa lukkojen takana. Ainoastaan tutkimusryhmän jäsenillä on pääsy tutkimusaineistoihin sekä oikeus käyttää niitä.

Tutkittavilta kerätyt kyselylomakkeet tuhotaan viimeisen aineistonkeruuajankohdan jälkeen 2021. Tällöin kaikki tutkimusaineisto on koodattu sähköiseen muotoon.

Menettelyt, joiden kohteeksi tutkittavat joutuvat

Tutkittavat pyritään rekrytoimaan eri puolelta Suomea (maaseutu, pienet kaupungit, suuret kaupungit). Tutkittavat rekrytoidaan siten, että tämän tutkimusprojektin tutkijat ottavat yhteyden mahdollisten koulujen rehtoreihin, joilta kysytään halukkuutta osallistua tutkimukseen. Mikäli halukkuutta löytyy, ottavat tutkijat yhteyden liikuntaa opettaviin opettajiin, joiden kanssa he sopivat käytännön asioista liittyen aineiston keruuseen. Vanhempien lupa lapsen osallistumiseen kysytään tällä saatekirjeellä, jonka osallistujat palauttavat koululle omalle opettajalleen, joka kootusti toimittaa tutkimusluvat tutkijoille.

Tutkittaville toteutetaan mittaukset, joissa kartoitetaan heidän motorisia taitojaan sekä fyysistä kuntoaan. Lisäksi tutkittavilta kerätään kyselylomaketietoa liittyen heidän fyysisen aktiivisuuden määrään, harrastuneisuuteen, motivaatiokokemuksiin fyysistä aktiivisuutta, koululiikuntaa ja uutta Move! järjestelmää kohtaan. Lisäksi kouluilta kerätään oppilaiden kouluarvosanat ja mahdolliset valtakunnallisten tasokokeiden tulokset. Tutkittavien taustatiedoista mitataan pituus ja paino sekä kysytään ikä ja syntymäkuukausi. Syntymäkuukautta tarvitaan tutkimusaineiston analysoinnissa esimerkiksi iän vakioimiseen. Syntymäkuukausi arkistoidaan tutkimusaineistoon. Osalta tutkittavista viikon aikaista fyysistä aktiivisuutta kartoitetaan kiihtyvyysmittareiden avulla.

Projektin aikana mitattavat muuttujat:

Move! –mittaukset:
(http://www.edu.fi/move/move-mittaus)
-20 m viivajuoksu
-5-loikka
-Heitto-kiinniotto –yhdistelmä
-Kehon liikkuvuus
-Punnerrus
-Ylävartalon kohotus (vatsalihasten kestävyys)

Motivaatiomittaukset:
-Viihtyminen koululiikunnassa
-Motivaatio koululiikunnassa
-Ahdistus koululiikunnassa
-Koettu pätevyys
-Koululiikunnan motivaatioilmasto
-Psykologiset perustarpeet koululiikunnassa
-Tavoiteorientaatio

KTK –testi:
(http://www.valmennustaito.info/taito/ktk-testi/)
-Puomilla tasapainoilu taaksepäin
-Sivuttaissiirtyminen
-Esteen yli kinkkaus
-Sivuttaishyppely

Muut kyselylomakemittaukset:
-Tyypillinen liikunnan määrä
-Harrastuneisuus urheiluseurassa
-Kouluarvosanat/tasokokeet

Pituus ja paino

Objektiivinen fyysisen aktiivisuuden määrä viikon ajalta
-Actigraph kiihtyvyysmittarit (kuva 1).

Kuva 1. Actigraph kiihtyvyysmittari.

Actigraph kiihtyvyysmittari on vyötärölle kiinnitettävä fyysisen aktiivisuuden mittauslaite. Laitteen avulla saadaan tietoa koehenkilön liikkumisesta/inaktiivisesta ajasta. Tässä tutkimusprojektissa kyseinen mittalaite annetaan osalle tutkittavista seitsemän päivän ajaksi. Tutkijat toimittavat/hakevat laitteen koehenkilön koululta. Koehenkilöt pitävät laitetta vyötäisillään valveilla ollessaan seitsemän päivän ajan. Yöksi laite otetaan pois. Tutkijat toimittavat tarkemmat ohjeet laitteen käytöstä niiden oppilaiden vanhemmille, joita kyseinen mittaus koskee.

Tutkijat keräävät aineiston kouluilta. Keruu tapahtuu liikunta- tai muiden aineiden tunneilla koulupäivän aikana. Yksi testikerta kestää noin kolme tuntia. Edellä mainitut muuttujat tullaan keräämään 5. -luokkalaisilta oppilailta vuosittain syys-lokakuussa, kunnes he ovat perusopetuksen yhdeksännellä luokalla vuonna 2021.

Tutkimuksen hyödyt ja haitat tutkittaville

Tutkimusprojektin aikana tutkittavat saavat tietoa heidän fyysisestä toimintakyvystään sekä sen kehittymisestä projektin aikana.

Move! mittaukset toteutetaan osana koulun normaalia toimintaa. Move! –mittaukset toteutetaan Opetushallituksen ohjeiden mukaisesti, joissa ensinnä kartoitetaan oppilaiden terveydentila (http://www.edu.fi/download/143901_move_opettajan_kasikirja_pdf.pdf). Ennen mittauksia oppilaille toteutetaan alkuverryttely, joka myös on Opetushallituksen ohjeiden mukainen. Kyseisten toimenpiteiden tarkoituksena on ennaltaehkäistä terveydellisiä haittoja tai loukkaantumisia mittausten aikana. On kuitenkin mahdollista, että fyysisten mittausten (Move!, KTK –testi) aikana tutkittava loukkaa lihaksensa tai nivelensä, vaikka kyseisten mittausten aikana ko. riski on erittäin pieni. Tutkijoina emme myöskään näe, että kyselylomake- tai fyysisen aktiivisuuden mittauksista aiheutuisi tutkittaville minkäänlaista fyysistä, psyykkistä tai sosiaalista vaaraa. Tutkijat ovat suorittaneet ensiapukurssin ja tutkimustilanteissa on mukana ensiapulaukku.

Miten ja mihin tutkimustuloksia aiotaan käyttää

Tutkimusaineistosta julkaistaan kansainvälisiä tutkimusartikkeleita, kansallisia julkaisuja, kongressi- ja seminaariesityksiä sekä opinnäytetöitä. Tutkittaville tiedotetaan tuloksista koulujen kautta.

Tutkittavien oikeudet

Osallistuminen tutkimukseen on täysin vapaaehtoista. Tutkittavilla on tutkimuksen aikana oikeus kieltäytyä tutkimuksesta ja keskeyttää tutkimukseen osallistuminen missä vaiheessa tahansa ilman, että siitä aiheutuu heille mitään seuraamuksia. Tutkimuksen järjestelyt ja tulosten raportointi ovat luottamuksellisia. Tutkimuksesta saatavat tutkittavien henkilökohtaiset tiedot tulevat ainoastaan tutkittavan ja tutkijaryhmän käyttöön ja tulokset julkaistaan tutkimusraporteissa siten, ettei yksittäistä tutkittavaa voi tunnistaa. Tutkittavilla on oikeus saada lisätietoa tutkimuksesta tutkijaryhmän jäseniltä missä vaiheessa tahansa.

Vakuutukset

Koska tämä tutkimus on normaalia koulun toimintaa, ovat tutkittavat vakuutettu koulujen taholta.

Jyväskylän yliopiston henkilökunta ja toiminta on myös vakuutettu. Vakuutus sisältää potilasvakuutuksen, toiminnanvastuuvakuutuksen ja vapaaehtoisen tapaturmavakuutuksen.

Tutkimuksissa tutkittavat (koehenkilöt) on vakuutettu tutkimuksen ajan ulkoisen syyn aiheuttamien tapaturmien, vahinkojen ja vammojen varalta. Tapaturmavakuutus on voimassa mittauksissa ja niihin välittömästi liittyvillä matkoilla. Tapaturman lisäksi korvataan vakuutetun erityisen ja yksittäisen voimanponnistuksen ja liikkeen välittömästi aiheuttama lihaksen tai jänteen venähdysvamma, johon on annettu lääkärinhoitoa 14 vuorokauden kuluessa vammautumisesta. Korvausta maksetaan enintään kuuden viikon ajan venähdysvamman syntymisestä. Voimanponnistuksen ja liikkeen aiheuttaman venähdysvamman hoitokuluina ei korvata magneettitutkimusta eikä leikkaustoimenpiteitä.

Tapaturmien ja sairastapausten välittömään ensiapuun mittauksissa on varauduttu tutkimusyksikössä. Tutkittavalla olisi hyvä olla oma henkilökohtainen tapaturma/sairaus- ja henkivakuutus, koska tutkimusprojekteja varten vakuutusyhtiöt eivät myönnä täysin kattavaa vakuutusturvaa esim. sairauskohtauksien varalta.

Tutkimuksesta on täytetty henkilötietolain edellyttämä rekisteriseloste, jonka tutkittava halutessaan saa tutkijoilta nähtäväkseen.

Tutkittavan huoltajan suostumus tutkimukseen osallistumisesta

Olen perehtynyt tämän tutkimuksen tarkoitukseen ja sisältöön, kerättävän tutkimusaineiston käyttöön, tutkittaville aiheutuviin mahdollisiin haittoihin sekä tutkittavien oikeuksiin ja vakuutusturvaan. Voin halutessani peruuttaa tai keskeyttää huollettavani osallistumisen tai kieltäytyä hänen tutkimukseen osallistumisesta missä vaiheessa tahansa. Suostun, että huollettavani osallistuu tutkimukseen annettujen ohjeiden mukaisesti. Huollettavani tutkimustuloksia ja kerättyä aineistoa saa käyttää ja hyödyntää sellaisessa muodossa, jossa yksittäistä tutkittavaa ei voi tunnistaa.

Huollettavani nimi:__________________________

Huoltajan allekirjoitus:_______________________

Pyydämme ystävällisesti toimittamaan tämän saatekirjeen huollettavanne kautta hänen opettajalleen.

____

Päiväys   Tutkijan allekirjoitus

APPENDIX 3. **Differences in motor competence, cardiorespiratory fitness and MVPA between adolescents who wore actigraphs and who did not**

Measure-ment	Year	Wearers in 2017	Non-wearers in 2017	Sig.	Wearers in 2021	Non-wearers in 2021	Sig.
Throw-catch	2017	10.97 (5.14)	10.02 (5.33)	**.003**	11.35 (4.97)	10.33 (5.29)	.443
	2018	13.52 (4.44)	12.41 (4.89)	**<.001**	14.03 (3.99)	12.78 (4.78)	**.044**
	2019	11.75 (4.79)	10.38 (4.87)	**<.001**	12.94 (4.04)	10.77 (4.91)	**.028**
	2020	13.57 (4.35)	12.45 (5.06)	**.001**	14.48 (3.67)	12.78 (4.87)	**.006**
	2021	14.59 (4.06)	12.69 (4.79)	**<.001**	14.67 (4.04)	13.26 (4.67)	.228
Side-to-side	2017	75.77 (12.99)	73.72 (13.11)	**.011**	77.40 (12.83)	74.35 (13.10)	.059
	2018	82.53 (13.98)	78.18 (13.56)	**<.001**	82.92 (13.92)	79.71 (13.87)	.078
	2019	89.86 (13.67)	87.81 (15.09)	**.044**	93.56 (12.47)	88.25 (14.65)	**.005**
	2020	95.05 (13.98)	91.23 (15.38)	**<.001**	96.39 (12.26)	92.46 (15.04)	.057
	2021	89.49 (14.99)	93.16 (17.15)	**<.001**	102.43 (14.07)	94.31 (14.07)	**<.001**
5-leaps	2017	7.76 (.89)	7.72 (.89)	.434	7.79 (.90)	7.73 (.89)	.640
	2018	8.32 (1.00)	8.13 (1.01)	**.004**	8.39 (1.10)	8.19 (1.00)	.141
	2019	8.65 (1.05)	8.52 (1.12)	.101	8.71 (1.19)	8.57 (1.08)	.306
	2020	8.98 (1.27)	9.00 (1.19)	.830	8.92 (1.10)	8.99 (1.24)	.633
	2021	9.58 (1.33)	9.15 (1.44)	**<.001**	9.18 (1.30)	9.33 (1.42)	.476
Shuttle run test	2017	36.67 (18.04)	35.67 (18.52)	.384	36.07 (17.09)	36.06 (18.42)	.996
	2018	40.83 (20.21)	40.48 (20.43)	.794	39.70 (18.38)	40.68 (20.47)	.717
	2019	40.26 (19.88)	38.25 (19.35)	.160	41.24 (20.15)	38.91 (19.54)	.366
	2020	43.52 (21.76)	43.52 (21.76)	.419	45.63 (20.54)	43.98 (22.16)	.594
	2021	43.84 (20.85)	39.31 (22.69)	**.041**	46.37 (20.92)	40.27 (22.21)	.077
MVPA	2017				61.87 (23.81)	58.23 (22.81)	.249
	2018				58.69 (21.84)	54.30 (20.58)	.173
	2019				52.00 (21.40)	53.18 (21.92)	.740
	2020				60.39 (28.04)	56.14 (24.45)	.382
	2021				51.64 (24.20)		

Note 1. Wearers = participants who wore actigraphs, non-wearers = adolescents who did not wear actigraphs.

Note 2. Bolded values indicate significance smaller than p = .05.

ORIGINAL PAPERS

I

DEVELOPMENT OF CHILDREN'S ACTUAL AND PERCEIVED MOTOR COMPETENCE, CARDIORESPIRATORY FITNESS, PHYSICAL ACTIVITY, AND BMI

by

Kolunsarka, I., Gråstén, A., Huhtiniemi, M., & Jaakkola, T., 2021

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Development of children's actual and perceived motor competence, cardiorespiratory fitness, physical activity, and BMI.

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Running head: Physical activity and BMI.

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Abstract

Purpose

To examine synergistic associations between developmental trajectories of motor competence, perceived motor competence, cardiorespiratory fitness, moderate-to-vigorous physical activity (MVPA), and body mass index (BMI) from late childhood to adolescence.

Methods

In this three-year follow-up study, motor competence, perceived motor competence, cardiorespiratory fitness, MVPA, and BMI were assessed in 1 167 Finnish school-aged children (girls = 583, boys = 565; Mage = 11.27 ±0.33). MVPA was measured using hip-mounted accelerometers. Developmental trajectories were analyzed using latent growth curve modeling.

Results

The development of motor competence, cardiorespiratory fitness and BMI was positive over time, whereas the development of perceived motor competence and physical activity was negative. The development of BMI was inversely associated with the development of cardiorespiratory fitness and physical activity.

Conclusion

In the transition from late childhood to adolescence, motor competence, cardiorespiratory fitness, and BMI increased, and perceived motor competence and physical activity decreased. However, individual variance in the developmental trajectories was significant. Moreover, children with a greater increase in BMI showed a greater decrease in cardiorespiratory fitness and physical activity from late childhood to adolescence.

Key words: Longitudinal, trajectories, person-oriented approach, latent growth modeling, childhood, adolescence.

Introduction

Obesity is a major health problem globally that has also accelerated in both children and adolescents over recent decades (1). Changes in global food systems and eating behaviors combined with sedentary behaviors have been the main drivers of this trend (2). The current low level of physical activity among children and adolescents (3) is alarming, as the foundations for a physically active lifestyle are laid in childhood (4) and physical activity plays an important role in the prevention of overweight and obesity in children and adolescents (5). These considerations call for more comprehensive investigations into the mechanisms behind the synergistic development of physical activity and BMI in childhood and adolescence (6).

The Developmental Model of Stodden et al. (6, 7), focusing on the role of motor skill competence in physical activity, is a model that describes the dynamic and reciprocal roles of motor competence, perceived motor competence, health-related fitness, physical activity engagement, and weight development in children. According to Stodden et al. (2008) (6) and Robinson et al. (2015) (7), in middle and late childhood, children with higher motor competence which has been conceptualized as fundamental movement skills (stability, locomotor, and object control skills) (8), are better able to engage in different physical activities. The model also suggests that health-related fitness, meaning a set of physical qualities (cardiorespiratory and muscular fitness, joint flexibility, and body composition) (9), acts as a mediator by enabling continued physical activity for longer periods of time, which in turn offers more opportunities for the development of motor competence. Another mediator between motor competence and physical activity engagement proposed by Stodden et al. (2008) (6) is perceived motor competence, which has been conceptualized as children's perceptions of their own motor competence (10). In middle and late childhood, children who demonstrate lower motor competence will also develop lower perceived motor competence, and hence lack the confidence to move and participate in physical activities, as they are more conscious that they will not be successful (6, 7).

Research has demonstrated that motor competence is one of the cornerstones of a physically active lifestyle (6, 7). More specifically, in their systematic review, Logan et al. (2015) (11) found a positive association between motor competence and physical activity from childhood to adolescence. In addition, longitudinal study designs have shown associations between motor competence and the development of BMI in both late childhood and adolescence (12, 13).

Health-related fitness is related to overall health (8) and physical activity engagement (14). Britton et al. (2020) (15) showed that health-related fitness was the strongest predictor for future physical activity in the transition from primary to secondary school. Moreover, cardiorespiratory fitness, in particular, has been found to be inversely related to BMI (16). Longitudinal studies have also shown that a smaller change in developmental pathways (12) or a lower level of cardiorespiratory fitness (17) increases the risk for becoming overweight or obese during childhood.

Perceived motor competence was found in a meta-analysis by Babic et al. (2014) (18) to be one of the strongest cognitive antecedents of physical activity engagement in children and adolescents. Perceived motor competence has also been found to be negatively associated with BMI in cross-sectional studies (19, 20).

The present model of Stodden et al. (2008) (6) has been commonly used to examine physical activity engagement and weight development in childhood (12, 13, 16, 21, 22). However, none of the previous studies have longitudinally assessed all the variables presented in the model of Stodden et al. (2008) (6). Moreover, most of the studies that have used the developmental model, have utilized variable-oriented statistical methods (22). Variable-oriented methods generate the mean slope of the sample and treat differences between individuals as error variance. Instead, a person-oriented method, such as latent growth modeling, allows for inferences about individuals and thus captures individual variances in trajectories over time. Rather than focusing on homogeneous average values, it is important to allow for inter-individual variability in, for example, children's developmental trajectories, as each one manifests a unique developmental trait (12, 22). It should be recognized that most studies in the field of motor development have focused on changes in childhood. However, the transition to adolescence, during which several important physical, psychological, and social changes occur (23), is marked by a rapid decline in physical activity (24). This study is the first to examine synergistic associations between developmental trajectories of motor competence, perceived motor competence, cardiorespiratory fitness, MVPA and BMI from late childhood to adolescence.

The aim of this study was twofold: first, to examine developmental trajectories of motor competence, perceived motor competence, cardiorespiratory fitness, MVPA and BMI, and second, to analyze the reciprocal relationships between these different developmental trajectories from late childhood to adolescence. Based on previously established relationships, we hypothesized that the development of BMI (25), cardiorespiratory fitness (26) and motor competence (27, 21) would be positive, whereas the development of MVPA (28, 24) and perceived motor competence would be negative (29). Moreover, the development of BMI was expected to be inversely associated with the development of cardiorespiratory fitness (12, 16) motor competence (13) and MVPA (28, 30), whereas the development of MVPA would be associated with the development of motor competence (7, 11) and cardiorespiratory fitness (14).

Methods

Participants

A total of 1 167 children (girls = 583, boys = 565) participated in this four-phase follow-up study between 2017 and 2020. Participants were recruited from 35 randomly selected elementary schools from four provinces of Finland. The schools were selected in order to reflect the proportion between students and the population of each province. Every 5^{th} grade student (Mage = 11.27) of the selected schools was invited to participate in the study. Participants included 2 % of all Finnish 5^{th} grade students (a total of 61 062 5^{th} grade children in 2017). The data of each time-point (T0-T3) were collected by the researchers during school hours between August and October in 2017-2020, precisely one, two, and three years after the baseline measurements. The researchers conducted motor competence, anthropometric (height and weight) and cardiorespiratory fitness measurements during PE classes and the questionnaire was administered in the classroom setting. Accelerometers were issued to a sample of participants (n = 663), of whom 591 expressed willingness to wear activity monitors over a period of one week at each time-point. Instructions were given in a letter to the participant and to the participant's parents. Informed written consents from parents or guardians and a verbal consent from the students were obtained prior to the start of the study. The study was approved by the human research ethics committee to the local University.

Measurements

Motor competence. Participants' motor competence was assessed via a throwing-catching combination (31). Participants were instructed to throw a tennis ball directly at a target area 1.5 x 1.5 meters square marked on a wall at 90 centimeters above floor level and to catch the ball after one bounce back from the floor. Throwing distance ranged from 7 to 10 meters depending on the participant's grade and gender. Each measurement comprised 20 trials and the result was the sum of successfully completed throw-catch combinations. This test is used extensively in Finnish sport science studies (22) and has shown an acceptable test-retest reliability (ICC = 0.692, p = 0.000) in children and adolescents (31).

Cardiorespiratory fitness. Participants' cardiorespiratory fitness was assessed with a 20-meter shuttle run test (32). In this test, participants ran continuously along a 20-meter track marked out on the floor by two parallel lines 20 meters apart. Running pace for each 20-meter shuttle was set by the frequency of recorded beeps. Initial running velocity was 8.5 km/h for the first minute, increasing by 0.5 km/h after each successive minute. The test finished when the participant was no longer able to keep pace with the beeps. The result was the number of shuttles run.

Perceived motor competence. Participants' perceived physical competence was assessed using the Finnish version of the sport competence dimension of the Physical Self-Perception Profile (PSPP) (33). Each item was preceded by the stem: "*What am I like*?" and all five items of the PSPP were rated on a five-point scale (e.g., 1 = *I'm among the best when it comes to athletic ability … 5 = I'm not among the best when it comes to athletic ability*). A previous study with Finnish children demonstrated acceptable construct validity (CFI = .98, TLI = .97, RMSEA = .074) and internal consistency (Cronbach's alpha .90) (34).

BMI. Participants' BMI was calculated using a weight (kg) and height (m) formula (kg/m^2) (35). Height was measured to the nearest .1 cm using portable measuring equipment. Body weight was measured to the nearest .1 kg using calibrated scales, with the children wearing light clothing and barefoot. Extended international (IOTF) body mass index cut offs values were used to determine participant's weight status (normal weight / overweight) (36).

Device-measured MVPA. Participants' MVPA was measured using Actigraph wGT3X+ accelerometers. An actigraph accelerometer was issued to participants for seven consecutive days. Participants were instructed to wear the device on their right hip at all times during their waking hours, except while bathing or during water-based activities. Data were collected as raw accelerations at a frequency of 30 Hz, standardly filtered, and converted into 15-s epoch counts. Customized Visual Basic Macro for Excel software was used for data reduction. A valid day of physical activity monitoring included measured values ≥500 min/day for at least two weekdays and one weekend day between general waking hours (i.e., 7:00-23:00). Periods of 30 min of consecutive zero counts were defined as non-wear time, and values over 20 000 counts per minute (cpm) were considered spurious accelerations and discarded (37). Cut points (38, 39) were used to calculate MVPA (≥2296 cpm).

Data Analysis

The data were examined for normality, outliers, and missing values. Correlations and descriptive statistics, including means and standard deviations, were computed for observed variables. In addition, Cronbach alphas were determined for the perceived competence scale. Parallel latent growth curve models were used to answer the research questions. The latent variables (slope and level) and the residuals were estimated based on the observed variables. In this context, level refers to the initial points at the baseline and slope to the rate of change in the observed variables over time. The default models for longitudinal development were constructed by fixing the loadings of the latent variables to 1 on the initial level, and from 0 to 3 (T0-T3) on the growth variables. (40). A statistical power analysis suggested that the minimum number of participants to be obtained should be 290 to meet statistical constraints with a confidence level of 95% and a margin of error $p < .05$. Thus, the current sample size of 1 167 was adequate for the main analyses of this study.

The Chi-square test ($\chi 2$) was used to evaluate the model's overall goodness-of-fit to the data. A non-significant difference between the observed and theoretical distributions indicated an acceptable fit to the data. To determine the appropriateness of the model, the standardized root mean square residual (SRMR), root mean square error of approximation (RMSEA), comparative fit index (CFI) and Tucker-Lewis index (TLI) were examined. A cutoff value close to .08 for SRMR indicates acceptable magnitude of a varying quantity, and a value of .06 or less for the RMSEA indicates an excellent fit of the model in relation to the degrees of freedom. CFI and TLI indices greater than .95 are indicative of an excellent model fit. The Missing Completely at Random (MCAR) test and descriptive statics were performed using SPSS Version 26.0 and all subsequent analyses using Mplus Version 8.6.

Results

Descriptive statistics are presented in Table 1. Visual inspection of the data revealed that the data were normally distributed and, based on the standardized values (± 3.00), did not include significant outliers. Missing values (6 606 out of 22 173) accounted for 29.8 % of the data matrix, mainly because accelerometers could not be provided for all participants and also because some participants did not wear the accelerometer for a valid period. Thus, some MVPA scores were missing. However, the MCAR-test ($x^2(28) = 30.32$, p = .348) showed that the MVPA data of participants with and without missing scores were equal. MVPA was measured each year but owing to low participation (n = 131), the fourth measurement did not fit into the model, and hence only the first three measurement points were analyzed. The MCAR test ($\chi^2(6606) = 6954{,}383$, $p = .001$) showed that the data matrices with and without missing scores were unequal (41). Closer examination of the data indicated that missing values were missing at random (MAR), as the missing scores did not represent any specific school or group and the student population across schools was relatively heterogeneous. Missing values were not imputed; instead, the statistical program used in the analysis estimated missing scores using mixture likelihood procedures, which has been shown to produce reliable parameter estimates and standard errors under MAR conditions (42).

The correlations between motor competence, perceived motor competence, cardiorespiratory fitness, MVPA, and BMI varied from weak to moderate (Table 2). BMI was negatively correlated with all the other variables. The strength of the correlation between motor competence and MVPA decreased over time, whereas the strength of the correlation between perceived motor competence and MVPA increased. The participants' mean age was 11.27 (±0.33) years, mean BMI 18.88 (±3.12) kg/m^2 and 22.4 % were overweight or obese at baseline (T0). The Cronbach's alphas of the perceived competence scale were high at each measurement point (T0 = .87, T1 = .90, T2 = .89, T3 = .89).

The parallel latent growth curve model of BMI, perceived motor competence, motor competence, MVPA, and cardiorespiratory fitness was estimated to detect a reciprocal relationship between the baseline levels (level) and changes (slope) from T0 to T3. The model showed acceptable fit for the present data (Table 3).

Latent growth curve (slope) means indicated, that over a three-year period (T_0-T_3), BMI ($slope_0$), motor competence ($slope_2$), and cardiorespiratory fitness ($slope_4$) increased while perceived motor competence ($slope_1$) and MVPA ($slope_3$) decreased (Table 3, Appendix 1).

The changes in MVPA ($slope_3$) and cardiorespiratory fitness ($slope_4$) were negatively associated with the change in BMI ($slope_0$), indicating that as BMI increased, MVPA and cardiorespiratory fitness decreased. The change in cardiorespiratory fitness was positively associated with the change in motor competence and perceived motor competence, meaning that as cardiorespiratory fitness increased, motor competence and perceived motor competence followed the same increasing pattern. Some other significant relationships between the latent variables were also detected (Table 3).

Squared multiple correlations revealed that the model strongly explained the variance in BMI (T0 = 98%, T1 = 91 %, T2 = 90 %, T3 = 90 %), perceived competence (T0 = 55 %, T1 = 61 %, T2 = 63 %, T = 74 %), motor competence (T0 = 62 %, T1 = 61 %, T2 = 54 %, T = 67 %), MVPA (T0 = 64 %, T1 = 60 %, T2 = 70 %) and cardiorespiratory fitness (T0 = 81 %, T1 = 69 %, T2 = 76 %, T3 = 82 %).

Discussion

This study sought to gain insights into developmental changes in motor competence, perceived motor competence, cardiorespiratory fitness, MVPA, and BMI in children from late childhood to adolescence. Therefore, a latent growth model was employed to examine developmental changes in variables, as this approach captures individual variance in these trajectories. The main finding was that a greater increase in BMI was associated with a greater decrease in cardiorespiratory fitness and MVPA across the three-year period. However, the great variance in the development of BMI, cardiorespiratory fitness and MVPA over time indicated the extent of the differences between individuals, which may also reflect differences in timing and pace of maturation (43). Moreover, contrary to the hypothesis, the development of MVPA was not associated with the development of cardiorespiratory fitness or motor competence.

This study demonstrated an increasing trend in BMI from late childhood to adolescence. This was expected, as it is evident that BMI in childhood changes substantially with age and maturation (25, 43) This result showed significant variances between individuals in the development of BMI over time, as also found by Rodrigues et al. (2016) (12). However, the study of Rodrigues et al. (2016) (12) was conducted with elementary students, whereas in this study the participants were older. Thus, the variance in the development of BMI may be explained by the differences in timing and pace of maturation, as the maturation is characterized by changing body composition and stature. Moreover, differences in BMI between sexes tend to rise in adolescence. (43). However, excess weight accumulation in childhood and early adolescence is a multifaceted phenomenon that is also affected by multiple genetic and non-genetic factors, such as environment, socioeconomic status, physical activity, and diet (44).

This study revealed a decreasing trend in MVPA, as also shown by a recent meta-analysis (24) and an empirical study by Janssen et al. (2019) (28). The period from late childhood to adolescence is characterized by multiple physical, psychological, and social changes (23) that are known to be associated with physical activity behavior. According to a recent systematic review (45), highly and moderately active children often undergo developmental change (usually a decline) in physical activity, whereas inactives tend to remain at same level. Thus, physical activity trajectories vary across individuals, as also manifested in this study in the significant variance between children in their MVPA trajectories. However, the change in physical activity does not tell the whole truth. Although active children face a decrease in the level of physical activity, it remains higher than that of originally passive ones. (45).

In this study, motor competence increased over time. This positive development is in line with the findings of the systematic review and meta-analysis conducted by Barnett et al. (2016) (27), who concluded that age is the most consistent correlate of all aspects of motor competence. However, motor competence does not automatically develop with age; instead, to achieve persistent change (46), motor skills need to be taught, reinforced, and repeated (47). This study, in line with Coppens et al. (2019) (21), found significant variance between the children's motor development trajectories, indicating that, over time, differences in motor competence development will become increasingly evident between children who have had enriched and varied movement experiences and those who have not (47). Furthermore, the individual timing and pace of maturation may have influenced development of motor competence, both via motor coordination (48) and increased body weight (49).

The development of cardiorespiratory fitness was positive over time, supporting the established fact that in childhood cardiorespiratory fitness increases with age. However, the timing and pace of change are highly individual. (26) Thus, as expected, variances in the developmental traits of cardiorespiratory fitness were observed over time, of which differences between sexes and maturation-driven changes in body composition may explain a portion (43, 50). Moreover, cardiorespiratory fitness can also be further improved with systematic training and everyday physical activity (26). It should be noted that although cardiorespiratory fitness may reflect past physical activity, most of its benefits only accumulate with sustained vigorous activity (51).

The development of perceived motor competence was negative over time, as also found by Britton et al. (2019) (29). The timing of puberty has been shown to be associated with decreased perceived athletic competence (52). Moreover, some previous studies have shown that as children age, their perception of their own motor competence becomes more accurate; thus, as children age, they tend to form a more realistic estimate of their abilities (6, 7). However, the systematic review and meta-analysis of De Meester et al. (2020) (10) found no age effect to support this theory.

The second research question was to examine the reciprocal relationships between the developmental trajectories of motor competence, perceived motor competence, cardiorespiratory fitness, MVPA, and BMI. The focus was on the developmental patterns of MVPA and BMI, as physical activity has a synergistic relationship with motor competence, perceived motor competence, and cardiorespiratory fitness (6) and also plays a role in the prevention of overweight and obesity in children and adolescents (5).

As expected, children with a greater increase in BMI showed a greater decrease in MVPA, providing further evidence of a developmental association between BMI and physical activity in childhood and adolescence (28). The systematic review by Poitras et al. (2016) (30) revealed that most of the cross-sectional studies reported a favorable association between BMI and MVPA, whereas longitudinal studies reported conflicting results on the relationship between MVPA and adiposity outcomes. The fundamental reason for increasing fatness is an imbalance between energy intake and energy expenditure over time, which may occur as energy expenditure decreases with reduced MVPA (53). Interestingly, the decrease in physical activity has also been explained as a result of weight status, not vice versa (54). As BMI increases, greater energy expenditure is demanded for a given amount of movement (55); this may facilitate faster fatigue, especially in vigorous physical activity, and thus lower the total amount of MVPA. Previous research (56) supports the idea that there may be a bidirectional relationship between weight status and physical activity, which enhances a self-perpetuating vicious circle of obesity and physical inactivity. Likewise, Stodden et al. (2008) (6) argued for unhealthy weight status as an outcome, which feeds back into the model, continuing to load negatively on factors influencing engagement in physical activity. The conclusion of the present study is that the association between the development of MVPA and BMI is reciprocal from late childhood to adolescence.

As expected, children with a greater increase in BMI faced a greater decrease in cardiorespiratory fitness. This finding supports previous longitudinal studies (12, 16, 17). Lima et al. (2017) (16) revealed that VO_{2peak} had the largest total association with body fatness. Rodrigues et al. (2016) (12) found that a negative developmental pathway (low rate of change) of cardiorespiratory fitness was associated with higher odds ratios for overweight/obese status at the end of primary school. Conversely, the recent study by Lopes et al. (2020) (13) found no significant differences in the developmental trajectories of cardiorespiratory fitness between two classes of children with lower or higher BMI development. However, the sample size was small and the class with higher BMI development contained fewer children. The reciprocal nature of the association between the development of BMI and cardiorespiratory fitness may be explained by metabolic cost. Children with higher BMI need to induce greater oxygen uptake for physical activities. Thus, they expend a larger proportion of their cardiorespiratory reserve when performing the same task as their leaner peers. (55). McGavock et al. (2009) (17) examined weight gain in low and high cardiorespiratory fitness groups over a 12-month follow-up. They found that the children in the low cardiorespiratory fitness group gained significantly more weight (17). However, maturation status may have influenced the association between BMI and cardiorespiratory fitness, especially in girls, as puberty-related increase in fat percentage may be related to decline in weight-relative fitness, such as running (43). In conclusion, the association between BMI and HRF may be reciprocal, indicating that cardiorespiratory fitness and BMI may form a self-perpetuating vicious cycle.

Several previous longitudinal studies have shown that the development of motor competence is associated with the development of adiposity (12, 13). However, although expected, this association was not found in this study. One explanation may be the absence of locomotor skill measurements in this study. Locomotor skills, such as hopping, require the movement of body mass through space, and hence excess mass has a negative influence on performance (43). Moreover, no longitudinal association was found between changes in perceived motor competence and BMI, despite the association between these variables found in previous cross-sectional studies (19, 20). Previous studies have shown a positive association between motor competence and physical activity behavior (7). However, no significant association between developmental trajectories was observed in this study. This may indicate that although physical activity decreases, motor competence generally remains unchanged (46). In addition, in contrast to a previous finding that vigorous physical activity was more strongly associated with cardiorespiratory fitness than less vigorous physical activity (51), MVPA was not associated with change in cardiorespiratory fitness in the present study.

The strengths of this study are the large number of participants, a longitudinal design with annual follow-ups, and the use of person-oriented latent growth modeling, which captures individual differences in trajectories over time. Furthermore, the analysis included all the variables presented in the commonly used developmental model of Stodden et al. (2008) (6) and provided further information on the reciprocal relationships between different developmental trajectories. However, the study has its limitations. The model lacked locomotor, stability, and muscular strength measurements, thus health-related fitness only included cardiorespiratory fitness, and motor competence only included object control. In addition, the fourth measurement of MVPA could not be included in the model owing to the participant attrition. The lack of maturation status measurements is a notable limitation because maturation is characterized by several physiological and psychological changes that may influence an individual's developmental trajectories of BMI, motor competence, perceived motor competence and cardiorespiratory fitness, and their associations (43). While BMI is a widely used measure in tracking changes in adiposity, it is not unproblematic with children and adolescents due to maturational growth and its inability to differentiate muscle mass from fat (35). However, according to previous studies, adiposity change in children should rather be measured with BMI, than BMI z scores (57)

In this longitudinal study from late childhood to adolescence, BMI, cardiorespiratory fitness, and motor competence increased while MVPA and perceived motor competence decreased. Moreover, the variances between subjects were significant in every trajectory, indicating that children develop unique traits depending on their psychological, physiological, and social surroundings. As shown in this study a greater increase in BMI was associated with a greater decrease in MVPA and cardiorespiratory fitness. Unhealthy weight gain in late childhood and adolescence is a multifaceted phenomenon, which seems to be characterized by the negative development of cardiorespiratory fitness and MVPA. Interventions are needed to prevent or at least attenuate this unhealthy developmental trait. While the foundations for healthy weight development and a physically active lifestyle are formed earlier in childhood, a stronger focus on late childhood is called for, as it is a life phase characterized by multiple physical, psychological, and social changes. Thus, further longitudinal investigations are needed to examine the differences in developmental trajectories between children and adolescents with different developmental BMI traits. Moreover, future studies should include the evaluation of maturation and study its effects on development of motor competence, perceived motor competence, cardiorespiratory fitness, BMI, and physical activity.

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Conflict of Interest

The authors declare that there are no conflicts of interest. Authors do not have any professional relationships with companies or manufacturers who will benefit from the results of this study. The results of this study do not constitute endorsement by ACSM. Additionally, the authors declare that the results are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation

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II

ACTUAL AND PERCEIVED MOTOR COMPETENCE, CARDIORESPIRATORY FITNESS, PHYSICAL ACTIVITY, AND WEIGHT STATUS IN SCHOOLCHILDREN: LATENT PROFILE AND TRANSITION ANALYSES

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Abstract

Engagement in physical activity plays a central role in the prevention and treatment of childhood overweight/obesity. However, some children may lack the skills and confidence to be physically active. This three-years follow-up study aimed to form profiles based on cardiorespiratory fitness, actual motor competence, perceived motor competence, physical activity, and weight status, and to examine if these profiles remain stable from late childhood to early adolescence. All these variables were annually assessed in 1 162 Finnish schoolchildren (girls = 583, boys = 564, Mage = 11.27 ± 0.32 years). Latent profile analysis was used to identify profiles and latent transition analysis to examine the stability of latent statuses. Three profiles were identified: normal weight with high movement (NW/MOVE+), normal weight with low movement (NW/MOVE-) and overweight-obese with low movement (OW-OB/MOVE-). Profile memberships remained relatively stable over time, indicating that children with low actual and perceived motor competence, cardiorespiratory fitness, and physical activity in late childhood also tended to exhibit these characteristics also in early adolescence.

Key words: motor development, adolescence, children, physical activity

Introduction

Childhood obesity has increased globally over recent decades (NCD risk, 2017). Children with overweight/obesity are at risk for multiple health consequences (dos Santos et al., 2015) and are likely to become adults with overweight/obesity (Singh et al., 2008). Engagement in physical activity plays a central role in the prevention and treatment of childhood overweight/obesity (Mahumud et al, 2021). This has led to calls for further research into the mechanisms underlying the synergistic development of physical activity and a healthy weight status from late childhood to early adolescence (Stodden et al., 2008; Robinson et al., 2015; Barnett et al., 2021).

The conceptual model of Stodden et al. (2008) titled “A Developmental Perspective on the Role of Motor Skill Competence in Physical Activity” has been widely used to explain physical activity and weight development from childhood to adolescence (Robinson et al., 2015). It postulates motor competence (i.e., fundamental movement skills: locomotor, object control, and stability skills) (Goodway, Ozmun & Gallahue, 2021) as a driver of physical activity, and (self-)perceived motor competence (De Meester et al., 2020) and health-related fitness (i.e., cardiorespiratory fitness and muscular fitness) (Bouchard & Shephard, 1994) as mediators between actual motor competence and physical activity engagement. According to the model, reciprocal and dynamic relationships between these variables form either a positive spiral of engagement or negative spiral of disengagement that directs the development of body weight over time in childhood and adolescence. The model suggests that children with high actual and perceived motor competence and high health-related fitness can continue physical activity engagement for longer periods, which in turn gives them more possibilities for the further development of motor competence. Thus, they have the skills and confidence to be physically active, and thus enhanced possibilities to maintain a healthy weight status. In contrast, low actual and perceived motor competence and low health-related fitness may have the opposite outcomes. This in turn may lead to an unhealthy weight status, further straining the aforementioned variables (Stodden et al., 2008). The hypothetical theoretical relationships between the variables in the model have been demonstrated in many studies (Robinson et al., 2015). Overweight/obesity has consistently been associated with poor actual motor competence (Barnett et al., 2021), low cardiorespiratory fitness (Kolunsarka et al., 2021), low perceived motor competence (Jones et al, 2010) and low physical activity engagement (Janssen et al., 2019). However, a recent systematic review by Barnett et al. (2021) called for longitudinal studies across childhood and into adolescence that include all the variables presented in the conceptual model by Stodden et al. (2008), including multiple time points and controlling for potential confounding factors.

Research has shown that children present markedly different developmental trajectories of actual motor competence (Coppens et al., 2019), physical activity behavior (Lounassalo et al., 2019), cardiorespiratory fitness (Raghuveer er al., 2020), and body weight status (Oluwagbemigun et al., 2019) over time. This is one reason why studies utilizing sophisticated person-oriented statistical methods are needed. Unlike traditional variable-oriented methods, person-oriented methods (e.g., latent profile analysis) use latent variables and enable the description of population heterogeneity for example in individuals' developmental differences (Ferguson, Moore & Hull, 2020). Another advantage of using person-oriented statistical methods, when investigating a whole theoretical model such as that of Stodden et al. (2008), is that they allow longitudinal analysis of hypothesized dynamic and synergistic relationships between variables. To date, only a few longitudinal studies have used person-oriented methodologies including latent variables. Jaakkola et al. (2020; 2021) and Estevan et al. (2021), for example, found that children with high actual and perceived motor competence and high physical fitness displayed higher levels of physical activity and were more likely than other children to have a healthy weight status in childhood. Furthermore, Jaakkola et al. (2020)

identified a profile in which children’s levels of actual and perceived motor competence and fitness were significantly lower and who were less physically active than the two other profiles identified. Thus, these previous studies (Jaakkola et al., 2020; Jaakkola et al., 2021; Estevan et al., 2021) have provided support for the positive and negative spirals of engagement that direct the development of body weight over time in childhood and adolescence, as presented in the model of Stodden et al. (2008).

However, this one is the first study of children to apply latent profile analysis (LPA) utilizing all the variables in the model of Stodden et al. (2008) and, further, to use latent transition analysis (LTA) to examine to what extent children transition between the identified profiles from late childhood to adolescence. Moreover, this study includes sex as a covariate, because previous studies have shown gender differences in object control (Barnett et al., 2010) and cardiorespiratory fitness (Raghuveer et al., 2020), in which boys outperform girls. Thus, the aim of this study was to extend our understanding of the conceptual model of Stodden et al. (2008) using all the variables and implementing a longitudinal design with original collected data. The research questions were: 1) Can qualitatively distinct subgroups of children based on cardiorespiratory fitness, motor competence, perceived motor competence, physical activity, and weight status be identified? 2) Do these profiles remain stable over time?

Materials and methods

Participants and procedure

This three-year follow-up study was conducted in Finland during 2017-2020. Participants were recruited from 35 randomly selected elementary schools in four municipalities. All 5^{th} graders were given the opportunity to participate, and a total of 1 162 (girls = 583, boys = 564, Mage = 11.27 ± 0.32 years) volunteered. These children accounted for 2 % of the Finnish population of that age, and all samples were representative of their local population. Data on actual motor competence, cardiovascular fitness, and anthropometric measurements (height and weight) were collected annually between August and October over four consecutive years (T0-T3) by trained researchers during physical education classes. The questionnaire on perceived motor competence was administered in the classroom setting. Accelerometers were used to collect device-based moderate-to-vigorous physical activity (MVPA). Participants were instructed to wear accelerometers for one week during the annual data collection periods (T0-T3). Verbal consents were obtained from the participating children and informed written consents from their guardian prior to the start of the study. The study was approved by the human research ethics committee of the local university.

Measurements

Actual motor competence. Actual motor competence was measured using three skill tests including object control and locomotor skills. The throw-catch test (Jaakkola et al., 2012) was used to assess participants' object control skills. A target square (1.5 x 1.5 meters) was marked on a wall at 90 centimeters above floor level. Throwing distance depended on the participant's grade and sex and ranged from 7 to 10 meters. Participants were instructed to throw a tennis ball with their desired hand directly at the target and to catch the ball after one bounce back from the floor with one or both hands. Participants were allowed 20 trials and the result was the number of successfully completed trials (i.e., the ball hit the target and was caught after one bounce back from the floor). This test is widely used in Finnish sport science studies (Jaakkola et al., 2021) and has shown acceptable test-retest reliability ($ICC = .692$, $p < .001$) in children and adolescents (Jaakkola et al., 2012). Locomotor skills were assessed by the 5-leap test (Jaakkola et al., 2012) and two-legged side-to-side jump test (Kiphard & Schilling, 2007). The 5-leap test consists of five consecutive strides with feet together at the start and end of the five leaps. Participants were allowed to start the strides with their desired leg. The test was performed twice, and the better result (i.e., the overall distance covered in meters rounded to two decimals) was recorded. In the two-legged side-to-side jump, the participant jumped from side-to side over a low wooden beam with legs in parallel continuously for 15 seconds as fast as possible. The test is performed twice, and the result is the sum of the number of successful jumps in each trial.

Perceived motor competence. Participants' perceived motor competence was assessed using the Finnish version of the sport competence dimension of the Physical Self-Perception Profile (PSPP) (Fox & Corbin, 1989). Each of the five items (i.e., good at sport, athletic ability, confidence to move, among the best when it comes to joining sport activities, among the first to join in sport activities) was preceded by the stem: "*What am I like*?" and rated on a five-point scale (e.g., 1 = *I'm among the best when it comes to athletic ability*, 5 = *I'm not among the best when it comes to athletic ability*). A previous study with Finnish children demonstrated acceptable construct validity (CFI = .98, TLI = .97, RMSEA = .074) and internal consistency (Cronbach's alpha = .90) (Gråstén, 2014).

Cardiorespiratory fitness. The 20-meter shuttle run test (Leger & Lambert, 1982) was used to assess participants' cardiorespiratory fitness. A 20-meter track was marked on the floor by two parallel lines and the running pace for each 20-meter shuttle was determined by the frequency of recorded beeps. Participants were instructed to run continuously up and down the 20-meter track in time to the beeps. The initial running velocity was 8.5 km/h for the first minute, after which it increased by 0.5 km/h for each successive minute. When participants were no longer able to keep pace with the beeps, they were instructed to terminate the test. The result was the number of completed shuttles.

Weight status. Participants' body mass index (BMI) was calculated using a weight (kg) and height (m) formula (kg/m^2). Body weight was measured to the nearest 0.1 kg using calibrated scales (Point Electronic Personal Scale), with the children wearing light clothing and barefoot. Height was measured to the nearest 0.1 cm using portable measuring equipment (measuring tape). Extended international body mass index cut-offs values (IOTF) were used to determine participants weight status (thinness, normal weight, overweight, obese) (Cole & Lobstein, 2012).

Device-measured MVPA. Participants' MVPA was measured using Actigraph wGT3X+ accelerometers. Participants were instructed to wear the device for seven consecutive days on their right hip at all times during their waking hours, except while bathing or doing water-based activities. Data were collected as raw accelerations at a frequency of 30 Hz and converted into 15-s epoch counts. Customized Visual Basic Macro for Excel software was used for data reduction. A valid day of physical activity monitoring included measured values ≥500 min/day for at least two weekdays and one weekend day between general waking hours (i.e., 7:00-23:00). Periods of 30 min of consecutive zero counts were defined as non-wear time, and values over 20 000 counts per minute (cpm) were considered spurious accelerations and discarded (Heil, Brage & Rothney, 2012). Cut points (Evenson et al., 2008) were used to calculate MVPA (≥2296 cpm).

Data analysis

Data were examined for normality, outliers, and missing values. Correlations and descriptive statistics including means and standard deviations were computed for the observed variables. In addition, Cronbach alphas were determined for the perceived competence scale. To conduct a latent transition analysis, a 5-step model was applied following the procedures of Nylund, Asparouhov & Muthén (2007) (cross-sectional data diagnosis and exploration using latent profile analysis (Step 1), testing for longitudinal measurement invariance (Step 2), defining latent statuses (Step 3), testing latent statuses for multiple-group latent transition analysis and transition probability invariance (Step 4), and testing latent transition analysis with the covariate sex (Step 5)).

In Step 1, to identify childhood movement profiles, a cross-sectional LPA was conducted for each time point (T0-T3). The explorative analyses were conducted for models including two to five profiles at each time point. Several indices were used to compere the models and thus to confirm the most reasonable model with optimal number of profiles. Statistical indicators included the Bayesian information criterion (BIC), the adjusted BIC (ABIC), Akaike's information criterion (AIC), entropy, and the adjusted Lo-Mendell-Rubin likelihood ratio test (ALMR-LTR). Models with low BIC, ABIC, and AIC indices and higher entropy were considered to show better fit to the data. In the ALMR-LTR, a p-value > .05 suggested that the k-pattern solution did not fit to the data any better than the k-1 solution (Nylund, Asparouhov & Muthén, 2007). Additionally, to avoid problematic models, profiles containing less than 1% or 5% of participants were identified and excluded. Once the most reasonable model was chosen, based on these several indices, a descriptive label was given to each profile and ANOVAs with post hoc were conducted to identify statistical differences in each variable between classes per time point.

In Step 2-4, the LTA, which is a longitudinal extension of the LPA method, was used to examine the stability of the profiles and the probabilities of changes in profiles over time. In Step 2, structural differences between the profiles at different time points were tested. Thus, to explore if the profile indicators provided an unbiased reflection of the same construct across time, longitudinal measurement invariance was tested by comparing the measurement invariance model (equal indicator means) with the measurement variance model (freely estimated profile indicator means). The Chi square ($\chi 2$) -test was conducted using the maximum likelihood estimator (MLR) with Satorra-Bentler scaling correction to evaluate the two models. In Step 3, the most reasonable solution was chosen for further analyses (i,e., if the models differed significantly, the measurement variance model was chosen) and the latent statuses were defined. In Step 4, the transition probability invariance was explored by fixing the transition probabilities to be equal over time and by comparing it to the freely estimated model. Finally, in Step 5, the covariate sex was added to the selected model. Results were considered statistically significant at the p < .05 level. Latent profile and latent transition analyses were performed by using Mplus version 8.2 and descriptive statistics, anova with post hoc and the missing completely at random (MCAR) test by using SPSS 22.0.

Results

Preliminary analysis

Tests of normality demonstrated that the data were approximately normally distributed (p > .05) and based on the standardized values (± 3.00) the data was free of outliers. As it was not possible to provide all the participants with accelerometers and the proportions of students completing all the measurements were lower at the later time points, missing values (9 651 out of 33 698) accounted for 28 % of the data. The Missing Completely at Random (MCAR) test indicated that the missing values ($\chi^2(9051) = 8494$, $p < .001$) were missing at random (MAR). Moreover, a closer examination of the data matrix revealed that the missing values did not represent any specific group or school. Consequently, the missing values were not imputed but were estimated through the mixture likelihood procedure, which has been shown to produce reliable parameter estimates and standard errors under MAR conditions (Hunt & Jorgensen, 2003).

Descriptive statistics

Descriptive statistics, including means, standard deviations, and proportion of students at each time point are shown in Table 1. A statistical power analysis suggested that to meet statistical constraints with a confidence level of 95% and a margin of error of p < .05, a minimum of 289 participants was required. Thus, the current sample size of 1 162 was adequate for the main analyses of this study. At baseline the participants' mean age was 11.27 ± 0.33 years and mean

BMI 18.88 ± 3.12 kg/m2. At baseline (T0) 4.4 % of the participants were thin, 73.2 % normal weight, 18.5 % overweight and 3.7 % obese. The Cronbach's alphas for the perceived competence scale were relatively high at each time point (T0 = .87, T1 = .90, T2 = .89, T3 = .89).

Latent profile analysis (Step 1)

Students were clustered into homogeneous profiles at each time point (T0-T3) based on actual motor competence, perceived motor competence, cardiorespiratory fitness, weight status, and MVPA. Statistical indices (AIC, BIC, aBIC, ALMR-LTR and entropy) showed that the three-profile model was the most reasonable at T0, T1 and T3. At each of these time points, the three-profile model produced more optimal statistical indicators than two-profile model, whereas four-profile model did not fit the data any better than three-profile model ($p > .05$). In addition, the three-profile models did not include classes containing less than 5 % of participants. At T2, the four-profile model indicated the best statistical fit but one of the classes contained less than 5 % of the participants, and therefore, the three-profile model was selected (Table 2). The selected 3-3-3-3-model comprised three latent profiles at each time-point (T0-T3).

Longitudinal measurement of invariance for the 3-3-3-3-model (Step 2)

Longitudinal measurement invariance was examined for the 3-3-3-3-model by comparing the measurement invariance model (equal indicator means) and the measurement variance model (freely estimated profile indicator means). The χ^2-test using the maximum likelihood estimator (MLR) with Satorra-Bentler scaling correction indicated that the full non-invariance model exhibited improved fit over the 3-3-3-3-model (Table 2). This result was expected given the large number of parameters and the developmental changes occurring over time in childhood (Putnick & Bornstein, 2016). Thus, the full non-invariance model was selected for subsequent transition analysis.

Definition of latent statuses (Step 3)

After careful examination of the models, the 3-3-3-3-model with freely estimated means was selected for further analysis. The next step included more specific reportage of the three clusters. Means and standard deviations of actual motor competence (locomotor and object control skills), perceived motor competence, cardiorespiratory fitness, MVPA and weight status prevalence were determined for each cluster and are presented in Table 3. Profile 3 was labelled normal weight with high movement (NW/MOVE+). The participants in this profile were mostly identified as normal weight or thin as less than 5 % was overweight or obese, and showed statistically significantly higher values in motor competence, cardiorespiratory fitness, MVPA and perceived motor competence at each time-point compared to their peers in the other two profiles. The profile 1 was labelled overweight/obese with low movement (OW-OB/MOVE-) as no children within this profile were identified as normal weight or thin, and the profile 2 was labelled normal weight with low movement (NW/MOVE-) as less than 4 % of the participants in this latter profile were overweight and none were identified as obese. The participants in the OW-OB/MOVE- profile were overweight and showed significantly lower values in locomotor competence and in the cardiorespiratory fitness measurements than their peers in the NW/MOVE- profile, although they showed significantly higher values in object control skills at T0, T1 and T3. No statistically significant differences were observed in MVPA or perceived motor competence between the OW-OB/MOVE- and NW/MOVE- profiles over time.

Latent status and transition probability invariance tests (Step 4)

The transition probability invariance result indicated that the model with transition probabilities fixed to be equal over time and the freely estimated model differed from each other. This result was expected given the large number of parameters and the developmental changes occurring over time in childhood (Putnick & Bornstein, 2016). As the freely estimated model allows for variation, it was chosen for further use. Thus, the results are based on a non-invariance model (i.e., the freely estimated model). Examination of the transition probabilities revealed that transition patterns were stable over time, indicating that participants remained in the clusters identified during the first measurement phase (Table 4).

Covariate effect of sex (Step 5)

To determine covariate effects of sex on status prevalence at T0-T3, sex was added to the 3-3-3-3 model as a covariate with free transition probabilities (Table 5). In a multinomial model, the analysis does not provide regression coefficients for the reference group. Significant covariate effects of sex on status prevalence were found for the memberships of the OW-OB/MOVE- and NW/MOVE- profile at T0 and NW/MOVE- profile at T2. The odds ratios indicated that girls were mostly likely to be in the NW/MOVE- profile at T0 and least likely to be in NW/MOVE+. At T2 girls were more likely to be in NW/MOVE- profile than in two others. There was no sample variance of sex at T1, indicating that girls and boys had an identical likelihood for cluster membership at T1, and thus sex effects were restricted.

Discussion

This study sought to profile children into homogeneous latent profiles and to explore their probabilities to transition between these profiles over three years from late childhood to early adolescence. The main finding based on actual and perceived motor competence, cardiorespiratory fitness, physical activity, and weight status was the identification of three latent profiles: OW-OB/MOVE-, NW/MOVE- and NW/MOVE+. This study also found that the profile memberships remained relatively stable over the three-year follow-up.

The participants in the NW/MOVE+ profile were normal weight and showed the highest values in all measurements, except in BMI. Compared to the other two profiles, their test results were significantly higher in actual and perceived motor competence, cardiorespiratory fitness, and

MVPA. Similar profiles were found by Estevan et al. (2021) and Jaakkola et al. (2020), both of whom reported one profile with high actual and perceived motor competence and high physical fitness. Estevan et al. (2021) also reported that this profile was characterized by the low membership of children with overweight/obesity and high engagement in physical activity. This profile demonstrates the positive spiral for engagement presented in the model of Stodden et al. (2008), positing that children with high actual and perceived motor competence and high cardiorespiratory fitness are more physically active and have a healthy weight status. Furthermore, according to Stodden et al. (2008), the children in this profile may have a lower risk for unhealthy weight development, as they have the tools to be physically active also later in life.

The participants in OW-OB/MOVE- and NW/MOVE- profiles had similar, although somewhat lower perceived motor competence and levels of MVPA, compared to their peers in the NW/MOVE+ profile. In addition, the participants in the OW-OB/MOVE- profile showed lower cardiorespiratory fitness and locomotor competence than those in the NW/MOVE- profile, but higher object control competence in T0, T1 and T3. As observed in previous studies (Moliner-Urdiales et al., 2011), children with overweight have a lower cardiorespiratory fitness than children with normal weight. Excessive body weight and/or fat mass increases the workload in the 20-meter shuttle run, which adversely affects test performance (Tomkinson et al., 2019). The participants in the OW-OB/MOVE- profile also showed significantly lower locomotor competence scores. However, poor performance in locomotor tasks such as jumping, and leaping may have less to do with motor coordination and more to do with the morphological limitations of overweight and obesity in transporting the body through space, and especially against gravity (Chivers et al., 2013; Webster et al., 2021). Overall, excess weight affects weight-bearing motor tasks, such as running and locomotion (Webster et al., 2021). In contrast, the children in the OW-OB/MOVE- profile showed significantly higher values for object control skills at the three time-points (T0, T1, T3) than their peers in the NW/MOVE- profile. This outcome contrasts somewhat with the findings of previous studies (D'Hondt et al., 2009; Gentier et al., 2013) comparing object control skills across different weight statuses, as they have concluded that children with obesity have lower scores in object control skills compared to their normal weight peers. However, D'Hondt et al. (2009) concluded that no differences in object control or motor skills in general were found between children with normal weight and overweight and thus suggested there may be certain cut-off from which movement difficulties appear. Also, previous studies have treated normal weight group as one homogeneous group (D'Hondt et al., 2009; Gentier et al., 2013), whereas this study showed that children with normal weight also have various levels of object control skills. Thus, children with normal weight may also have impaired object control competence, which may prevent them from being physically active in the future, as object control competence has been shown to be more strongly associated with physical activity levels than locomotor competence (Barnett et al., 2011). Moreover, according to Stodden et al. (2008), children in both the NW/MOVE- and OW-OB/MOVE- profiles may, owing to their low motor competence, be at higher risk for low engagement in physical activity, which in turn may lead to unhealthy weight development in the future.

The profile memberships identified in this study were relatively stable over time, suggesting that children in NW/MOVE- and OW-OB/MOVE- profiles with low actual and perceived motor competence, cardiorespiratory fitness, and physical activity in late childhood also tend to exhibit these characteristics in early adolescence. As in these profiles participants' level of actual and perceived motor competence remains relatively low, they are unlikely to be motivated to engage in physical activity either currently or later (Stodden et al., 2008; Robinson et al., 2015). Previous studies have also shown that weight status (Singh et al., 2008) and physical capabilities, such as physical fitness (True et al., 2021) and motor competence

(Jaakkola et al., 2021), tend to track from childhood to adolescence. Thus, it would be important to identify children with poor movement profiles as early as possible for example by systematic fitness and motor competence monitoring in schools and through actions and interventions in schools and communities seek to enhance children's motor competence and further engagement in physical activities.

Finally, the results indicated that at T0 and T2 girls were mostly likely to be in the NW/MOVE-profile than in the other two profiles. A previous finding that girls are less competent than boys in object control skills (Barnett et al., 2010) may, at least partially, explain this result. Girls have also been shown to be less physically active than boys (Guthold et al., 2020). Further conclusions on sex differences in profile membership cannot be drawn owing to the lack of social support variables in the current data, as it has been suggested social support is an important factor underlying participation in motor competence-related physical activities in school-aged children (Biddle et al., 2011).

The strengths of this study were the large number of participants, a longitudinal design with annual follow-ups, and the person-oriented statistical analyses. Moreover, the profile analyses included all the variables presented in the model of Stodden et al. (2008) and thereby providing further information on the model. However, the study has its limitations. Device-measured MVPA may be underestimated because water-based activities could not be recorded. While BMI is a widely used measure in tracking changes in adiposity, it is not unproblematic with children and adolescents due to maturational growth and its inability to differentiate muscle mass from fat (Nuttall, 2015). Also, the lack of maturation measurements is a notable limitation of this study, as maturation is characterized by several physiological and psychological changes that may over time influence an individual's BMI, actual motor competence, perceived motor competence and cardiorespiratory fitness developmental trajectories (Malina, Bouchard & Bar-Or, 2004). Perceived motor competence was assessed with the sport competence dimension of the Physical Self-Perception Profile (PSPP) by Fox & Corbin (1989), which is rather a measure of perceived sport/athletic competence than perceived motor competence. Therefore, caution should be exercised when comparing studies using different instruments to assess perceived motor competence (Estevan & Barnett, 2018).

The findings of this study extended our understanding of the variables included in the model of Stodden et al. (2008) and the role of weight status in this model from late childhood to early adolescence. To summarize, excessive body weight and/or fat mass is a burden which hinders performances in weight-bearing motor tasks. However, the fact that children with normal weight have very different movement profiles raises the concern that children with normal weight and a low movement profile may be at higher risk for unhealthy weight development in later life (Stodden et al., 2008; Robinson et al., 2015). Moreover, girls compared to boys were less likely to be in the high movement profile, which suggest that some gender differences can be seen in the development of physically active lifestyle. A suggestion for future studies is to repeat this study protocol in younger children and possibly follow them through adolescence. Moreover, future studies should include the examination of organized sport participation, as it seems to be important in this respect. To develop optimal overweight/obesity prevention programs, future studies should examine whether children with low movement profiles are at risk for low physical activity engagement and unhealthy weight development also in adulthood, so that resources can be targeted where they are most needed, such as children's motor competence development.

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Declaration of interest statement

The authors declare no competing financial or non-financial interests.

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III

IMPACT OF MOTOR COMPETENCE PROFILES ON ADOLESCENTS' PHYSICAL ACTIVITY AND CARDIORESPIRATORY FITNESS ACROSS FOUR YEARS

by

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Impact of motor competence profiles on adolescents' physical activity and cardiorespiratory fitness across four years.

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Abstract

Introduction

Physical activity levels have decreased over past decades with most adolescents neither meeting the current physical activity recommendations nor demonstrating adequate cardiorespiratory fitness. Motor competence (MC) is foundational for a physically active lifestyle; however, children demonstrate significant differences in their levels of MC in a broad foundation of movement skills. This study investigated developmental patterns of physical activity and cardiorespiratory fitness in children across 4 years based on their longitudinal MC profiles.

Methods

The data included annual measurements of MC, accelerometry-measured moderate-to-vigorous physical activity (MVPA), and cardiorespiratory fitness over 4 years from the age 11 to 15 ($n = 1147$, girls 582, boys 565). Latent profile analysis was used to identify longitudinal MC profiles and latent growth curve modeling to examine intercepts and slopes (s) of MVPA and cardiorespiratory fitness in these MC profiles.

Results

Three different longitudinal MC profiles were identified: low, moderate, and high. The MC profiles showed significant differences in intercepts of cardiorespiratory fitness and MVPA. The high MC profile showed the highest intercepts for both, but also a statistically significant decline in MVPA over time ($s = -3.36$, $p < .001$). Cardiorespiratory fitness increased similarly in all three profiles over time: low ($s = 1.20$, $p < .01$), moderate ($s = 1.28$, $p < .001$), high ($s = 2.21$, $p < .001$).

Conclusion

These results highlight the long-term associations between different MC profiles and development of MVPA and cardiorespiratory fitness. Adolescents with lower MC demonstrated lower levels of MVPA and cardiorespiratory fitness, indicating decreased participation in physical activities that can optimally enhance cardiorespiratory fitness. However, significant differences in MVPA levels between MC profiles faded over time in adolescence, whereas significant differences in cardiorespiratory fitness remained.

Key words: motor proficiency barrier, motor development, person-oriented, longitudinal study.

Introduction

Physical activity is important for a healthy lifestyle and for the prevention of overweight and obesity (1). Increasing the amount and intensity of physical activity also positively impacts cardiorespiratory fitness, and hence cardiometabolic health, in adolescents (2). As majority of youth do not meet current physical activity guidelines (3) nor demonstrate adequate cardiorespiratory fitness (4), it is important to identify the critical factors that impact long-term physical activity and fitness behaviors and habits (5, 6).

Motor competence (MC) refers to goal-directed movement skill levels that involve large muscle groups (7), including locomotor (moving the body from one place to another), object projection/control (ability to manipulate and project an object), and balance skills (ability to maintain a controlled body position during task performance) (8). While all children can develop MC through context-specific free play and structured physical activities (5), not all children reach the same level (9, 10) as not all may have the same opportunities to learn these skills (5). It is crucial to understand that the physical activity environment impacts not only the learning of MC skills, but also the amount and intensity (e.g., light, moderate, vigorous) of physical activity, which impacts cardiorespiratory fitness (5). Thus, while all physical activity is beneficial, exploring and learning a wide variety of movement skills and being able to transfer those skills to higher-level movement applications provides a diversified foundation for both directly (via greater neuromuscular demand) (11) and indirectly (via sustained activities associated with practice, gameplay, and performance) enhancing cardiorespiratory fitness (12). Better cardiorespiratory fitness allows children to continue physical activities for longer periods of time and thus provides more opportunities for motor development and physical activity accumulation (5, 7).

Physical activity levels tend to decrease across childhood (13), whereas cardiorespiratory fitness, enhanced by physiological growth and maturation, tends to increase (14). However, these trajectories show significant inter-individual variation (9, 15), which may partly be explained by different levels of MC (16). Previous reviews have concluded that MC is positively associated with physical activity (7, 17, 18) and cardiorespiratory fitness (17, 19, 20). However, understanding the skill level needed to facilitate enhanced physical activity and fitness trajectories remains unknown. In 1980, Seefeldt (21) introduced the idea of a motor skill proficiency barrier, below which individuals would find learning advanced skills more difficult. Haubenstricker and Seefeldt (22) also considered that adequate levels of MC are important for promoting successful participation in physical activities, specifically vigorous ones. Malina (23) also favored researching the idea of a motor skill proficiency barrier given the limited success of efforts to mitigate current negative trends in physical activity, fitness and increasing obesity levels in children and adolescents.

Previous longitudinal studies have reported less favorable development of cardiorespiratory fitness (9, 24, 25, 26) and physical activity (27, 28) in individuals with low MC. However, a recent systematic review (18) noted that further longitudinal evidence is required to demonstrate a direct pathway from MC to physical activity. Thus, the developmental pathways of physical activity and cardiorespiratory fitness based on different MC profiles over time may be better understood using person-oriented methods. This study is the first to identify data-driven longitudinal MC profiles for studying the latent growth curves of both device-measured physical activity and cardiorespiratory fitness. The study had three aims: 1) to identify and study subgroups of children based on their MC scores over four years; 2) to investigate intercepts and slopes of physical activity and cardiorespiratory fitness in each MC subgroup over four years; and 3) to examine the relationship between development of physical activity and cardiorespiratory fitness in each MC subgroup.

Methods

Participants

This four-year follow up study was conducted during 2017-2021 in four cities in south, north, central, and east Finland. Participants were all consenting 5th graders (n = 1147) in 35 randomly selected elementary schools and accounted for 2 % of the same-age Finnish population (Mage at baseline 11.37±0.33). All samples were representative of their local population. Data were collected five times in the years 2017-2021 (T0-T4) annually between August and October. Cardiorespiratory fitness, MC and anthropometric data were collected during school hours in indoor gym settings by trained researchers. Device-measured MVPA was assessed using accelerometers. Verbal consent from the participating children and written consent from their guardians was obtained prior to study start. The study was approved by the University of Jyväskylä ethics committee for human research.

Measurements

Motor competence (MC). In the first data collection (T0), participants performed the 5-leaps test, throw-catch combination and three KTK (Körperkoordinations Test für Kinder) (29) subtests: walking backwards, jumping laterally, and moving sideways. Thereafter, the 5-leaps test, jumping laterally and throw-catch combination were performed annually each fall (T1-T4). The *5-leaps* test was conducted by performing five consecutive horizontal jumps with joined feet position at the start. From the starting feet position, participants were instructed to jump forward using the leg of choice and, after four further leaps, land on both feet. The result was expressed in meters as the overall distance covered. The *throw-catch combination* was performed by throwing a tennis ball at a target square (90 cm x 90 cm) marked on a wall at 90 cm above floor level and then catching the ball after one return bounce. Both the 5-leaps and throw-catch combination tests are extensively used in Finnish sport science studies (30).

Participants were instructed to perform 20 trials and the result was the sum of successfully completed trials. Throwing distance depended on the participant's grade and gender and ranged from 7 to 10 meters. *Walking backwards* consisted of walking backwards on each of three balance beams 6 cm, 4.5 cm, and 3 cm wide, respectively. After a practice trial, participants were instructed to slowly walk backwards on the 6-cm beam, trying to avoid contact with the ground. 9 trials, 3 per beam were performed. The result was the sum of all error-free steps backwards across trials. The maximum score for each trial was 8, and thus the potential maximum score was 72. *Jumping laterally* consisted of jumping over a dividing line as quickly as possible for 15 seconds. Participants were instructed to take off from and land on both feet simultaneously. The result was the sum of jumps across two trials. *Moving sideways* required participants to move small wooden blocks in a sequence from left to right, continually placing the feet on the block just moved to the right. Participants were instructed to move the blocks as quickly as possible for a period of 20 seconds. The result was the number of moves summed across two trials. As the MC variables were not commensurate, they were standardized as Z-scores.

Cardiorespiratory fitness. The 20-meter shuttle run test (31) was used to assess cardiorespiratory fitness. Participants ran back and forth between two parallel lines 20 meters apart. The running pace for each 20-meter shuttle was determined by the frequency of recorded beeps. The initial running velocity was 8.5 km/h for the first minute, increasing by 0.5 km/h for each minute thereafter. The result was the number of completed shuttles. Participants were instructed to terminate the test when they were no longer able to keep pace with the beeps.

Device-measured MVPA. Participants' MVPA was assessed using Actigraph wGT3+ accelerometers. Participants were instructed to wear the accelerometer on their right hip for seven consecutive days. Accelerometers were removed while sleeping and bathing or doing water-based activities. Data were collected as raw accelerations at a 30-Hz frequency and converted into 15-s epoch counts. Data were reduced using Customized Visual Basic Macro for Excel software. A valid day of physical activity monitoring comprised measured values ≥500 min/day on at least two weekdays and one weekend day between normal waking hours (i.e., 7:00-23:00). Consecutive zero counts lasting 30 min were defined as non-wear time and values over 20 000 counts per minute considered spurious accelerations and discarded (32). Cut points from Evenson et al. (33) were used to calculate MVPA (≥2296 cpm).

Anthropometric measurements. Height was measured to the nearest .1 cm using portable measuring equipment. Body weight was measured to the nearest .1 kg using calibrated scales, with the children wearing light clothing and barefoot. Participants' body mass index was calculated using a weight (kg) and height (m) formula (kg/m^2). Participants peak height velocity was identified to predict maturity. The maturity offset was calculated using equation with age and height from T0 to T4 following the procedures of Moore et al. (34).

Data analysis

Descriptive statistics, including means and standard deviations, were calculated for the observed variables, and outliers and missing values were examined. For nested groups (i.e., different school classes, between-group differences in the observed motor competence, MVPA and cardiorespiratory fitness variables were analyzed using intraclass correlations (ICC). After the preliminary analysis, a two-step analysis (regression auxiliary model) was implemented to identify longitudinal MC profiles based on MC measurement z-scores at T0-T4 and to examine intercepts and slopes in MVPA and cardiorespiratory fitness in each MC profile. In the first analysis, MC latent profiles were estimated, and Bose-Chaudhuri-Hocquenghem (BCH) weights saved. In the subsequent analysis, latent growth curve models, using BCH weights, conditional on the MC latent profile variable, were estimated (35).

Latent profiles analysis aims to identify types or groups of people that have different configural profiles of personal attributes, such as motor skills (balance skills, locomotor skills, object control skills). Thus, mean Z-scores for all MC measurements at each time point (T0-T4) were entered simultaneously into the latent profile analysis. The analysis was conducted for from two to five profiles to confirm the optimal number of profiles. Statistical indicators included Akaike's information criterion (AIC), Bayesian information criterion (BIC), the adjusted BIC (ABIC), entropy, and the adjusted Lo-Mendell-Rubin likelihood ratio test (ALMR-LTR). Models with low AIC, BIC and ABIC indices and higher entropy indicate better fit to the data. In the ALMR-LTR, a p-value > .05 suggested that the k-pattern solution did not fit the data any better than the k-1 solution. Additionally, to avoid problematic models, profiles containing less than 5% of participants were excluded. After selecting the best-fitting model, based on these statistical indices, each MC profile was assigned a descriptive label. In the second analysis, latent growth curve models for physical activity and cardiorespiratory fitness were estimated to examine intercepts and slopes over time in each MC profile, where intercept describes the baseline from which the slope begins at T0, and slope describes the rate of change. ANOVA with Tukey's Post Hoc analyses was performed to identify statistical differences in variables' mean levels between the MC profiles. Logistic regression coefficients were used to estimate the odd ratios of the MC profiles to achieve MVPA guidelines. Descriptive statistics, ANOVA, logistic regression and the missing completely at random (MCAR) test were performed using SPSS 26.0. The model was estimated using Mplus Version 8.6.

Results

Descriptive statistics (means and standard deviations) for each measurement in each MC profile and the significant differences between profiles are presented in Table 1. Participants' mean age at baseline (T0) was 11.27 ±0.32 years. Correlations between MC variables and MVPA and cardiorespiratory fitness at each time point are presented in table 2. Correlations varied from low to moderate. The strongest correlations were found between cardiorespiratory fitness and the 5-leaps test. As the proportions of students completing all the measurements decreased annually, missing values (11 594 out of 32 116) accounted for 36 % of the data. However, closer inspection of the data revealed that the missing values were not attributable to any specific school or group. The Missing Completely at Random (MCAR) test indicated that missing values ($\chi^2(11\,607) = 10\,905$, $p < .001$) were missing at random (MAR). Missing values were assessed using the mixture likelihood procedure that has been shown to generate reliable parameter estimates and standard errors under MAR conditions (36). The data with nested groups, i.e., collected from school classes, were expected to display a hierarchical structure. The ICC p-values indicated small but significant variation between school classes in cardiorespiratory fitness and MC measurements (see Table 3). Thus, the regression auxiliary model was implemented using the complex model option to control for non-independence of observations due to nesting in school classes. As the number of participants willing to wear the accelerometer decreased annually, the differences between wearers and non-wearers at T4 was tested with the independent sample T-test. No significant between-group difference in MVPA was found at T0-T4.

Latent profile analysis. Latent profile memberships based on annual MC z-scores at T0-T4 were identified. As presented in table 4, with the increasing number of profiles from two to three AIC, BIC and ABIC indices decreased. However, after the three-profile solution, the AIC, BIC and ABIC indices decreased only marginally. The entropy was the highest in three-class solution. Although, the ALMR-LTR p-value (.066) suggested that three-profile solution did not significantly improve the model compared to two-profile solution, after careful consideration of all the indices together (AIC, BIC, aBIC, ALMR-LTR and entropy), the three-profile model was selected for further analysis. Profiles were derived from the MC z-scores for the 5-leaps, throw-catch combination, and jumping laterally tests at five time points (T0, T1, T2, T3, T4) and walking backwards and moving sideways tests at the first time point only (T0). As presented in table 1, the low MC profile contained about one-fifth, the moderate MC profile nearly half and the high MC profile 30 % of the participants. Both genders were almost equally distributed across all profiles and there were no significant differences in maturation offsets between profiles at T0-T4. BMI differed significantly between all three profiles at T0-T3, but at T4 only low MC profile differed significantly from other two (See table 1). The three MC profiles were labeled low, moderate, and high based on their MC mean values (see table 1) and z-score levels at each time point (see figure 1). Differences in mean MC scores for each assessment between profiles were significant, relatively large, and equal at each timepoint (see table 1). For example, in the throw-catch combination test, the mean annual score in the low MC profilers was 7.2/20 compared with the 15.6/20 in the high MC profilers. Thus, the low MC profilers' object control skills scores were 54 % lower than those of the high MC profilers. The difference in the 5-leaps test also favored the high MC profilers (9.5m vs. 7.4m). Thus, the low MC profilers' locomotor skill scores were 22 % lower than those of the high MC profilers.

MVPA and cardiorespiratory fitness based on MC profiles over time. Latent growth curves were estimated for each of the three MC profiles to examine intercepts and slopes of MVPA and cardiorespiratory fitness. Results showed that intercepts of MVPA and cardiorespiratory fitness were significantly different between MC profiles. Intercepts were lowest in the low MC profile and highest in the high MC profile (see table 5). The MVPA intercept was over 25 minutes higher in the high MC profile compared to the low MC profile. Slopes indicated that there were not significant changes in MVPA in the low or moderate MC profiles over time. However, the high MC profile showed a significant negative slope (s = -3.36) in MVPA, indicating that MVPA significantly decreased over time (from 70 to 56 min) (see figure 2). Mean MVPA levels were significantly different across all profiles at first three time points. At the fourth time point, only the difference between high and low MC profiles was significant and there were no significant differences between profiles at the last time point (see table 1). Depending on the year, 46-64 % of the high MC profilers engaged in over 60 minutes of MVPA per day, compared to 24-36 % of the moderate and 6-22 % of the low MC profilers (see table 1). Moreover, the odd ratios showed that the high MC children were 3.5 to 16 times more likely to meet the guidelines than their low MC peers (see table 1).

The CRF intercept was, on average, 32 laps higher in the high MC profile compared to the low MC profile. The slopes of cardiorespiratory fitness demonstrated statistically significant increase in each MC profile. There were no significant differences in slopes, indicating that cardiorespiratory fitness increased similarly in all three MC profiles (see table 5 and figure 3). Mean CRF levels were significantly different between MC profiles at all time points (see Table 1). Differences in laps across profiles were fairly consistent and ranged from 14 and 30 laps at each time point, representing differences in mean VO_2max estimates of up to 7 ml/kg/min between profiles (31).

A significant positive correlation ($r = .646$, $p < .01$) was found between the slopes in MVPA and cardiorespiratory fitness, but only in the high MC profile, indicating that the steeper the decrease in MVPA, the slighter the increase in cardiorespiratory fitness (see table 5).

Discussion

This study examined physical activity and cardiorespiratory fitness trajectories from late childhood to adolescence based on different longitudinal profiles of MC. A two-step model was applied to study both profiles and their distal outcomes. Three MC profiles were identified: low, moderate, and high. Differences in mean MC scores between profiles were significant and generally large and consistent over time, indicating MC levels are generally determined earlier in childhood. The intercept of MVPA at T0 was highest in the high MC profile (70.13 min/day), which was 14 more min/day and 25 min/day higher than intercepts of MVPA of the moderate

(56.67) and low MC profiles (44.82), respectively. The slope of MVPA was significant and negative only in the high MC group, resulting in that differences in mean MVPA levels between profiles were not significant at the last time point between profiles. Second, the cardiorespiratory fitness intercept was highest in the high MC profile and lowest in the low MC profile. Moreover, positive slope indicated that cardiorespiratory fitness increased in each profile, although the cardiorespiratory fitness slopes showed no significant inter-profile differences. Thus, mean cardiorespiratory fitness levels remained significantly different between profiles over time.

While childhood may be the most opportune time to develop competence in various motor skills (8), variation in the development of children's MC is dramatic (9, 10). Based on the literature, children with a low level of MC are at risk for low physical activity (6, 16, 18, 27, 28) and poor physical fitness (9, 19, 20, 24, 25, 26). However, none of these previous studies have studied the development of MVPA and cardiorespiratory fitness simultaneously. Our large longitudinal data sample indicated that children present different levels of MC over time and that children with low MC have both lower physical activity and lower cardiorespiratory fitness over time in adolescence.

The MC profiles significantly differed by their intercepts and annual mean levels of MVPA. These results support previous findings that children with lower levels of MC have lower levels of physical activity (6, 27), but also provided more detailed information about the differences in MVPA levels over time. The present study, depending on the year (T0-T3), found that mean MVPA level was 17 to 25 minutes/day more in the high MC profilers than in their low MC profile peers. Whereas for example, interventions aimed at improving physical activity in children have reported differences of 3-14 minutes per day between control and intervention groups (37). Thus, promoting motor competence in children should be considered as a possible tool to positively affect engagement in physical activity. At the last time point (T4) differences between profiles were not significant. However, the sample size at T4 was relatively small (n = 70), as the proportion of students willing to wear accelerometer decreased from year to year. Thus, the results should be addressed with caution. The inter-profile differences in physical activity levels demonstrate the potential importance of improving MC in all children. Furthermore, this difference is important, as previous studies have consistently shown strong evidence of a favorable relationship between physical activity and several cardiometabolic biomarkers and bone health in children (38). Janssen et al. (39) found that the least favorable cardiometabolic risk factor was observed in children whose mean MVPA was less than 60 min/day. The result of this study suggests, based on percentile of children reaching the recommendation that children in low MC profiles are more likely to demonstrate higher cardiometabolic health risk.

Although research generally demonstrates that children's physical activity decreases over time (13), the trend is not universal (40). The present results are unique, as no significant change in MVPA was observed over the four years in either the low or moderate MC profile, whereas the high MC profile showed a significant decrease. Lounassalo et al. (40), in a recent systematic review, reported similar results, showing that physical activity of highly and moderately active children often decreases, but generally remains higher than that of initially more passive peers. However, the result of this study showed that despite of having high MC, MVPA significantly decreased over time in adolescence and differences in physical activity levels between children with different MC levels diminished over time. Adolescents with high MC may have the skills and confidence to be more physically active than their peers with low MC (5), but that does not necessary mean they will be.

Intercepts as well as annual mean levels of cardiorespiratory fitness significantly differed between the MC profiles. The intercept of cardiorespiratory fitness was significantly lower in the low than other two MC profiles. Moreover, the moderate MC profile had a significantly lower intercept of cardiorespiratory fitness than the high MC profile. These findings are consistent with previous empirical studies have shown that children with lower MC have lower levels of cardiorespiratory fitness (24, 25, 26), but also provide more detailed information about differences in cardiorespiratory fitness levels over time. Differences in mean levels of cardiorespiratory fitness were significant and relatively large and consistent between MC profiles over time. Cardiorespiratory fitness has been shown to be independently associated with clustered cardiovascular disease risk in children (41). In 2016, Ruiz and his colleagues (41) published a meta-analysis that reported cardiorespiratory fitness cut points to avoid cardiovascular disease risk in children and adolescents. According to the cut points reported by Ruiz et al. (2016) (41), boys in the low MC profile had an elevated risk for cardiovascular disease at T1-T4, as on average, they fell below the cut points (30-47 laps). Girls in the low MC profile had an elevated risk for cardiovascular disease only at T4, as on average, they fell below the cut point (21 laps).

The present results also demonstrated that cardiorespiratory fitness generally increased with age. However, according to Raghuveer et al. (14) the rate of change partly depends on the ability to be physically active, which, in turn, may depend on one's MC level (5, 7, 17, 18). While the slope in cardiorespiratory fitness was more favorable in the high than in the other two MC profiles, the difference only trended towards significance ($p = .100$ and $p = .112$). A previous study by Hands (24) reported an increase in the difference between high and low MC groups in shuttle-run times over ten years. Thus, it is evident that children and adolescents with poor MC or low fitness are unlikely to catch up with their peers (24, 26, 41). Children with higher MC also demonstrate higher energy expenditure during object control skill performance due to the increased neuromuscular demands of higher-level performance (11). Moreover, participation in activities that require continued performance of object control skills offers greater opportunities for sustained participation (both in acute performance and over time) in different physical activities that enhance cardiorespiratory fitness (12). A recent meta-analysis (42) also suggested that improving fitness levels in youth may be associated with healthy weight maintenance and reduced cardiometabolic risk. Thus, adolescents' MC levels may impact their health parameters later in life (19, 20).

Studies have shown that physically active adolescents have higher cardiorespiratory fitness (14). However, the strength of the association has been small to moderate (43), which may be explained by insufficient vigorous physical activity in youth since cardiorespiratory fitness has been shown to be primarily related to vigorous physical activity (44). During adolescence, coupled with maturation and growth, adequate intensity physical activity function to increase cardiorespiratory fitness (14). In this study, MVPA either decreased or remained stable depending on the MC profile, whereas cardiorespiratory fitness increased in each MC profile. However, there was a significant positive association between the slopes of MVPA and cardiorespiratory fitness, but only in the high MC profile. One way to interpret this finding is that, although mean engagement in MVPA significantly decreased over time in high MC profile, those individuals who decreased less appeared to improve cardiorespiratory fitness more. Since previous studies have shown that vigorous physical activity may improve cardiorespiratory fitness (44), the absence of a significant association between slopes of MVPA and cardiorespiratory fitness in the low and moderate MC profiles may be due to a lack of vigorous physical activity. Blomqvist et al. (45), for example, found that children with higher MC also showed relatively higher vigorous physical activity.

This study provided some support for the potential existence of a motor proficiency barrier impacting healthy levels of physical activity and cardiorespiratory fitness (22). In this study, 83 % of the low MC participants did not meet the physical activity guidelines (60 min/day) at age 11, a proportion comparable to that reported by De Meester et al. (6), who noted that 89% did not meet the 60 min/day threshold. In contrast, 65% of the high MC children met the 60 min/day guideline at age 11. Moreover, the physical activity trajectory of the low MC children remained unchanged over the 4 years, and they also had the lowest levels of cardiorespiratory fitness over time. While we did not specifically test for a MC proficiency barrier, our data indicate that the low MC children (21 % of the sample) may have remained below such a barrier and thus had difficulty engaging in physical activity and promote cardiorespiratory fitness during late childhood and adolescence relative to peers with higher MC. In addition, their poor cardiorespiratory fitness indicates that they do not engage in enough vigorous physical activity (44), which may be a consequence of a lack of competence in a variety of skills and the ability to participate successfully with peers (11, 12, 46).

The multiple strengths of this study include a) 4-year longitudinal data, b) a large and representative cross-Finland sample, c) an objective MVPA measure, and d) the use of person-oriented analyses. Moreover, this is a novel design for investigating the associations of MC levels on physical activity and cardiorespiratory fitness trajectories. However, this study has its limitations. MC was evaluated only by product-oriented measurements, whereas the inclusion of both product- and process-oriented measures may yield a more comprehensive picture of MC (47). Moreover, objectively measured physical activity was based on a minimum three-day snapshot (two weekdays and one weekend day) and was not measured in all participants; thus, the findings should be interpreted with caution. Last, while longitudinal data does not demonstrate a causal impact of MC on MVPA and cardiorespiratory fitness (i.e., intervention), it is important to consider the physical activity context (46). Most physical activities that children engage in, require competence in a variety of movement skills (i.e., physical education, structured games, sports). Thus, higher levels of skill facilitate successful and continued participation in multiple types of activities over time and would impact physical activity and cardiorespiratory fitness both directly and indirectly (5, 11, 48). The differences in MC levels across profiles suggest that, indeed, skill levels were developed prior to age 11 in this study. To suggested physical activity (or fitness) promote MC, would be logical only if the context of the activity and the behaviors during it would be known (46). This argument supports our conclusion that MC is a critical antecedent for promoting and sustaining adequate physical activity and cardiorespiratory fitness levels across childhood and adolescence.

Conclusion

By highlighting the associations between MC and the intercept and development of MVPA and cardiorespiratory fitness, this study supports the conceptual model of Stodden et al. (5). To enhance physical activity and cardiorespiratory fitness in adolescents, an individual's level of motor competence should not be ignored as it also impacts perceptions of competence and the motivation to be physically active, both additional critical determinants of physical activity behaviors (49). Therefore, promoting physical activity in adolescents may require a more individualized approach focusing on their established competencies (or lack thereof), and motivational (autonomy) and social (relational) factors (50). Clearly, MC is not the only factor associated with physical activity and cardiorespiratory fitness development; thus, future studies should include other factors, such as motivation, social environment, and perceived competence in their analyses to further increase the understanding of individual differences between children with different physical activity habits.

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Conflict of Interest

The authors declare that there are no conflicts of interest. Authors do not have any professional relationships with companies or manufacturers who will benefit from the results of this study. The results of this study do not constitute endorsement by ACSM. Additionally, the authors declare that the results are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

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Figure 1. MC measurements’ mean standard scores at T0-T4 for each MC profile. *Footnote: Standard deviations of MC standard scores ranged between 0.6-1.0. W = Walking backwards, M = Moving sideways, L = 5-leaps, J = Jumping laterally, T = Throw-catch combination, MC = Motor competence.

Figure 2. Development of MVPA in each MC profile. *Footnote: vertical axis = min/day, red line = low MC profile, blue line = moderate MC profile, green line = high MC profile, MC = Motor competence, MVPA = moderate to vigorous physical activity.

Figure 3. Development of cardiorespiratory fitness in each MC profile. *Footnote: vertical axis = laps, red line = low MC profile, blue line = moderate MC profile, green line = high MC profile, MC = Motor competence.

Table 1. Descriptive statistics.

Measurement	Time	n	All M (SD)	Low MC profile M (SD)	Moderate MC profile M (SD)	High MC profile M (SD)
Object control skills: throw-catch combination (number of successful trials)	T0	1106	10.40 (5.28)	5.65 (4.46) M,H	9.98 (4.43) L,H	14.43 (3.82) L,M
	T1	970	12.86 (4.74)	8.21 (4.31) M,H	12.58 (4.04) L,H	16.31 (3.06) L,M
	T2	860	10.93 (4.88)	6.0 (4.05) M,H	10.49 (4.04) L,H	14.75 (3.36) L,M
	T3	779	12.91 (4.81)	7.79 (4.38) M,H	12.59 (4.02) L,H	16.50 (2.86) L,M
	T4	559	13.4 (4.83)	8.38 (4.61) M,H	13.03 (3.94) L,H	16.26 (.3.18) L,M
Locomotor skills: 5-leaps test (distance covered in meters)	T0	1099	7.74 (.89)	6.86 (.71) M,H	7.64 (.64) L,H	8.51 (.67) L,M
	T1	964	8.21 (1.01)	7.09 (.83) M,H	8.1 (.72) L,H	9.06 (.71) L,M
	T2	838	8.58 (1.10)	7.45 (.85) M,H	8.44 (.84) L,H	9.50 (.79) L,M
	T3	738	8.99 (1.22)	7.80 (1.09) M,H	8.83 (.95) L,H	9.97 (.94) L,M
	T4	539	9.31 (1.41)	7.97 (1.33) M,H	9.06 (1.11) L,H	10.22 (1.22) L,M
Locomotor skills: KTK jumping laterally (the sum of jumps across two trials)	T0	1089	74.55 (13.10)	60.93 (10.41) M,H	73.25 (9.56) L,H	85.96 (9.13) L,M
	T1	972	79.91 (13.88)	62.20 (9.29) M,H	78.65 (8.71) M,H	92.73 (9.38) M,H
	T2	848	88.65 (14.56)	72.01 (11.16) M,H	87.56 (10.65) M,H	101.40 (9.76) M,H
	T3	743	92.76 (14.94)	73.61 (16.33) M,H	92.72 (9.05) M,H	103.75 (9.89) M,H
	T4	527	95.10 (16.58)	79.10 (15.68) M,H	91.99 (14.13) M,H	106.37 (12.26) M,H
Locomotor skills: KTK moving sideways (sum of moves across two trials)	T1	1057	48.75 (9.46)	40.05 (8.15) M,H	47.98 (7.43) L,H	55.9 (7.48) L,M
Locomotor skills: KTK walking backwards (sum of error free steps across 9 trials)	T2	678	50.18 (13.94)	36.33 (13.18) M,H	49.01 (12.05) L,H	57.54 (10.72) L,M
MVPA (min/day)	T3	452	58.78 (22.96)	44.22 (16.69) M,H	55.26 (20.71) L,H	69.63 (23.13) L,M
	T4	285	55.08 (20.84)	43.94 (16.72) M,H	53.29 (19.45) L,H	62.97 (21.45) L,M
	T2	208	52.9 (21.75)	41.58 (16.59) H	50.42 (21.65) H	60.37 (21.30) L,M
	T3	130	57.48 (25.60)	46.41 (16.80) H	54.68 (26.20) L,H	63.66 (26.09) L
	T4	70	51.64 (24.20)	46.84 (31.08)	49.24 (22.97)	56.0 (23.47)
Percentage of participants achieving MVPA guidelines / odd ratio for achieving MVPA guidelines.	T0	452	43.36 %	17.11 % / ref	36.23 % / 2.75	63.91 % / 8.80
	T1	285	35.79 %	13.46 % / ref	30.77 % / 2.96	53.39 % / 8.00
	T2	208	32.69 %	5.88 % / ref	29.35 % / 6.65	47.56 % / 16.00
	T3	130	37.69 %	21.05 % / ref	30.19 % / 1.62	50.0 % / 3.75
	T4	70	32.86 %	22.22 % / ref	24.24 % / 1.12	46.43 % / 3.50
Cardiorespiratoy fitness (shuttles completed)	T0	1057	36.06 (18.33)	20.30 (11.34) M,H	34.24 (15.04) L,H	50.18 (16.86) L,M
	T1	933	40.62 (20.34)	24.06 (12.62) M,H	38.63 (17.62) L,H	53.98 (19.50) L,M
	T2	765	39.10 (19.58)	22.55 (11.74) M,H	36.63 (15.33) L,H	53.41 (19.90) L,M
	T3	673	44.12 (22.02)	25.89 (13.78) M,H	40.82 (17.95) L,H	60.85 (20.98) L,M
	T4	436	40.91 (22.14)	23.73 (13.36) M,H	37.88 (19.90) L,H	53.83 (21.54) L,M
Maturation offset	T0	1107	-1.30 (.80)	1.27 (.74)	-1.30 (.82)	-1.22 (-79)
	T1	1071	-.38 (.85)	-.36 (.78)	-.35 (.85)	-.43 (.88)
	T2	839	.54 (.90)	.52 (.81).	.57 (.89)	.51 (.95)
	T3	648	1.40 (.86)	1.32 (.74)	1.43 (.87)	1.40 (.91)
	T4	577	2.24 (.80)	2.28 (.77)	2.26 (.80)	2.19 (.83)
Body mass index (kg/m^2)	T0	1120	18.88 (3.12)	20.49 (4.10) M,H	18.85 (2.87) L,H	17.81 (2.08) L,M
	T1	1012	19.56 (3.41)	21.41 (4.35) M,H	19.57 (3.27) L,H	18.42 (2.31) L,M
	T2	836	20.32 (3.36)	21.83 (4.19) M,H	20.39 (3.31) L,H	19.32 (2.41) L,M
	T3	646	20.01 (3.37)	22.40 (4.28) M,H	21.08 (3.37) L,H	20.20 (2.51) L,M
	T4	578	21.44 (3.21)	23.57 (4.38) M,H	21.22 (2.99) L,H	20.78 (2.43) L

Note 1. M = mean, MC = motor competence, SD = standard deviation, MVPA = moderate-to-vigorous physical activity, ref = reference value, KTK = *Körperkoordinations Test* für Kinder.
Note 2. . The letters (L = low MC profile, M = moderate MC profile, H = high MC profile) indicate the profiles between which there is a significant difference $p < .05$

Table 2. Correlations between variables at each time point (T0-T4)

	Time	Object control skills: throw-catch combination	Locomotor skills: 5-leaps test	Locomotor skills: KTK jumping laterally	Locomotor skills: KTK moving sideways	Locomotor skills: KTK walking backwards	MVPA
Locomotor skills: 5-leaps test	T0	436***					
	T1	.398***					
	T2	.425***					
	T3	.401***					
	T4	.332***					
Locomotor skills: KTK jumping laterally	T0	.420***	.480***				
	T1	.428***	.567***				
	T2	.376***	.522***				
	T3	.461***	.498***				
	T4	.374***	.495***				
Locomotor skills: KTK moving sideways	T0	.403***	.439***	.562***			
Locomotor skills: KTK walking backwards	T0	.403***	.411***	.437***	.456***		
MVPA	T0	.352***	.325***	.265***	.266***	.165**	
	T1	.228***	.369***	.281***			
	T2	.289***	.304***	.232**			
	T3	.194*	.412***	.241**			
	T4	.340*	.275*	.108			
Cardiorespiratory fitness	T0	.471***	.580***	470***	.425***	.346***	.478***
	T1	.385***	.536***	.422***			.373***
	T2	.395***	.568***	.479***			.335***
	T3	.401***	.621***	.504***			.515***
	T4	.397***	.566***	.497**			.332***

Note 1. MVPA = moderate-to-vigorous physical activity, KTK = *Körperkoordinations Test* für Kinder.

Table 3. Intraclass correlation coefficients between classes from T0 to T4

	Grouping variable	Time	β	SE	p
MVPA	Class	T0	.04	.03	.133
		T1	.04	.04	.298
		T2	.07	.06	.279
		T3	.05	.11	.640
		T4	.02	.09	.844
Cardiorespiratory fitness	Class	T0	.10	.02	.000***
		T1	.03	.02	.087
		T2	.10	.03	.001**
		T3	.06	.03	.014*
		T4	.03	.03	.291
5-leaps	Class	T0	.08	.02	.001**
		T1	.10	.02	.000***
		T2	.08	.02	.000***
		T3	.03	.01	.030*
		T4	.09	.03	.001**
KTK: Jumping laterally	Class	T0	.14	.03	.000***
		T1	.27	.03	.000***
		T2	.14	.03	.000***
		T3	.09	.03	.000***
		T4	.14	.05	.002**
Throw-catch combination	Class	T0	.10	.03	.000***
		T1	.09	.02	.000***
		T2	.12	.03	.000***
		T3	.07	.02	.001**
		T4	.08	.03	.003**

Note 1. ***p < .001, **p < .01, *p < .05.
Note 2. SE = standard error, MVPA = moderate-to-vigorous physical activity, KTK = *Körperkoordinations Test* für Kinder.

Table 4. Profile class solution

Classes	Parameters	AIC	BIC	ABIC	LT 5 %	pLMR	Entropy
2-solution	19	36941.87	37204.21	37039.04	0	.019	.85
3-solution	**70**	**35569.75**	**35922.89**	**35700.55**	**0**	**.066**	**.86**
4-solution	88	35185.96	35629.91	35350.39	0	.453	.82
5-solution	106	34830.40	35365.16	35028.47	0	.620	.81

Note 1. Bold indicates the most reasonable solution.
Note 2. AIC = Akaike Information Criterion, BIC = Bayesian Information Criterion, ABIC = Adjusted Bayesian Information Criterion, LT = less than, pLMR = p-value for Adjusted Lo-Mendell-Rubin Ratio Test.

Table 5. The parameter estimates for parallel latent growth curve models of each MC profile.

		Low MC profile	Moderate MC profile	High MC profile
MVPA	Intercept (SD)	44.82 (1.46) *** MH	56.67 (1.56)*** LH	70.13 (1.89)***LM
	Slope (SD)	.89 (.18) H	-1.44 (1.14)	-3.36 (.73)*** L
Cardiorespiratory fitness (CRF)	Intercept (SD)	20.00 (.11)*** MH	34.94 (.83)*** LH	52.00 (1.04)***LM
	Slope (SD)	1.20 (.14)**	1.28 (.29)***	2.21 (.52) ***
Correlation	$Slope^{CRF}$ / $Slope^{MVPA}$	-.385	.245	.646**

Note 1. CRF = Cardiorespiratory fitness, MVPA = moderate-to-vigorous physical activity, SD = standard deviation, MC = motor competence.
Note 2. $^{***}p < .001$, $^{**}p < .01$, $^{*}p < .05$.
Note 3. The letters (L = low MC profile, M = moderate MC profile, H = high MC profile) indicate the profiles between which there is a significant difference p < .05

Figure 1.

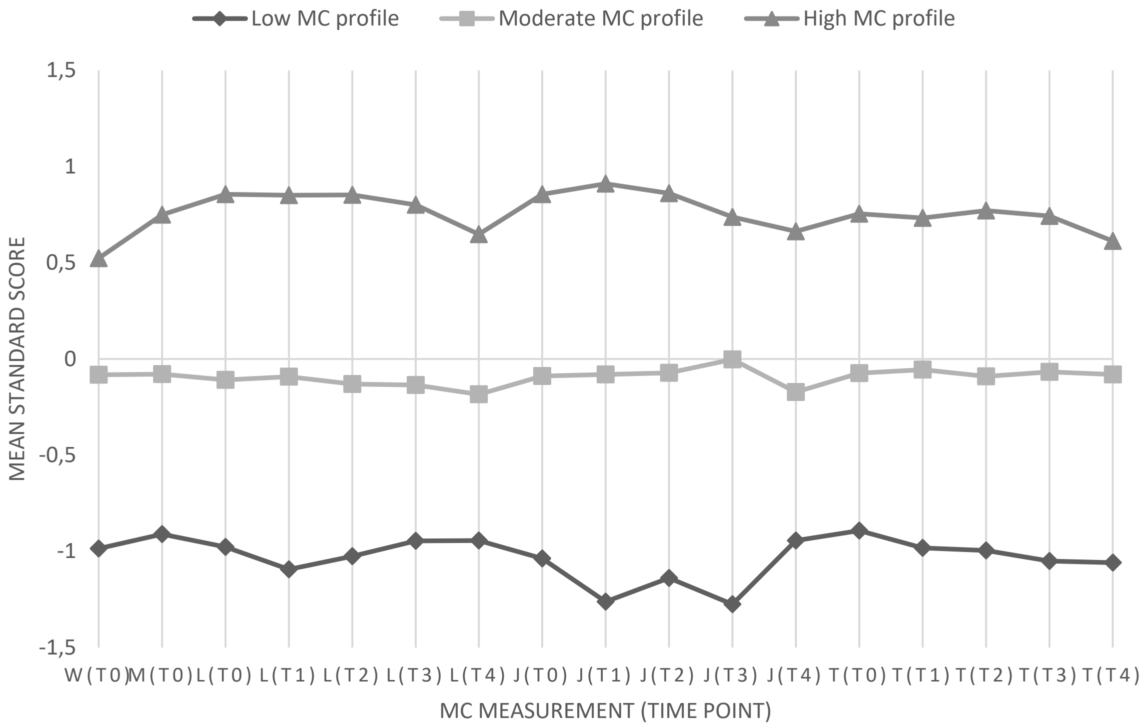


Figure 2

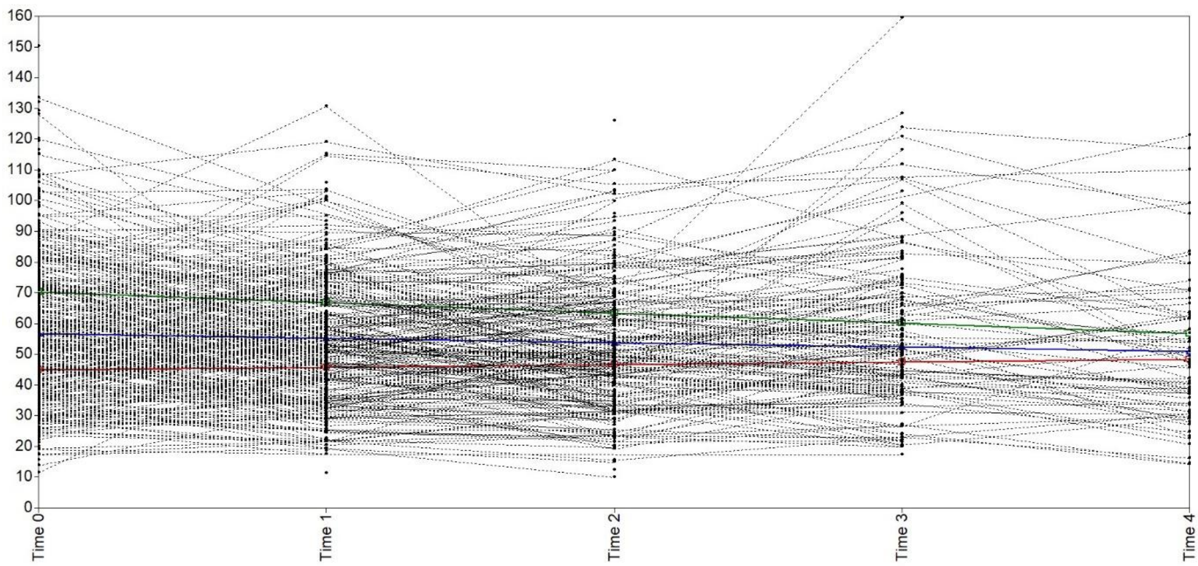
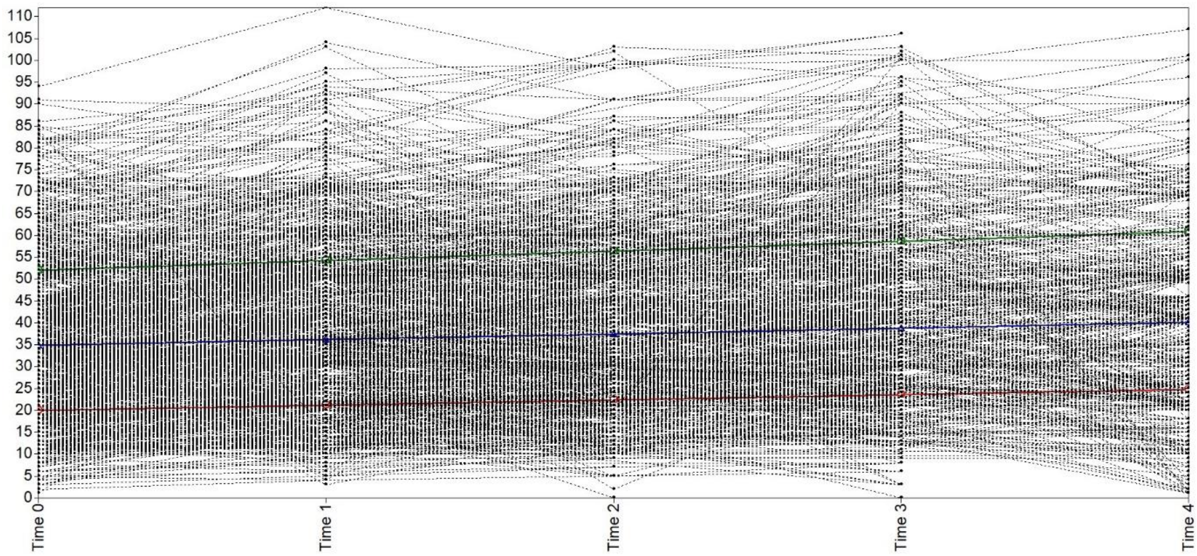


Figure 3



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Time 1
Time 2
Time 3
Time 4

IV

THE ASSOCIATIONS BETWEEN ORGANIZED SPORT PARTICIPATION AND PHYSICAL FITNESS AND WEIGHT STATUS DEVELOPMENT DURING ADOLESCENCE

by

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Submitted.

Request a copy from the author.