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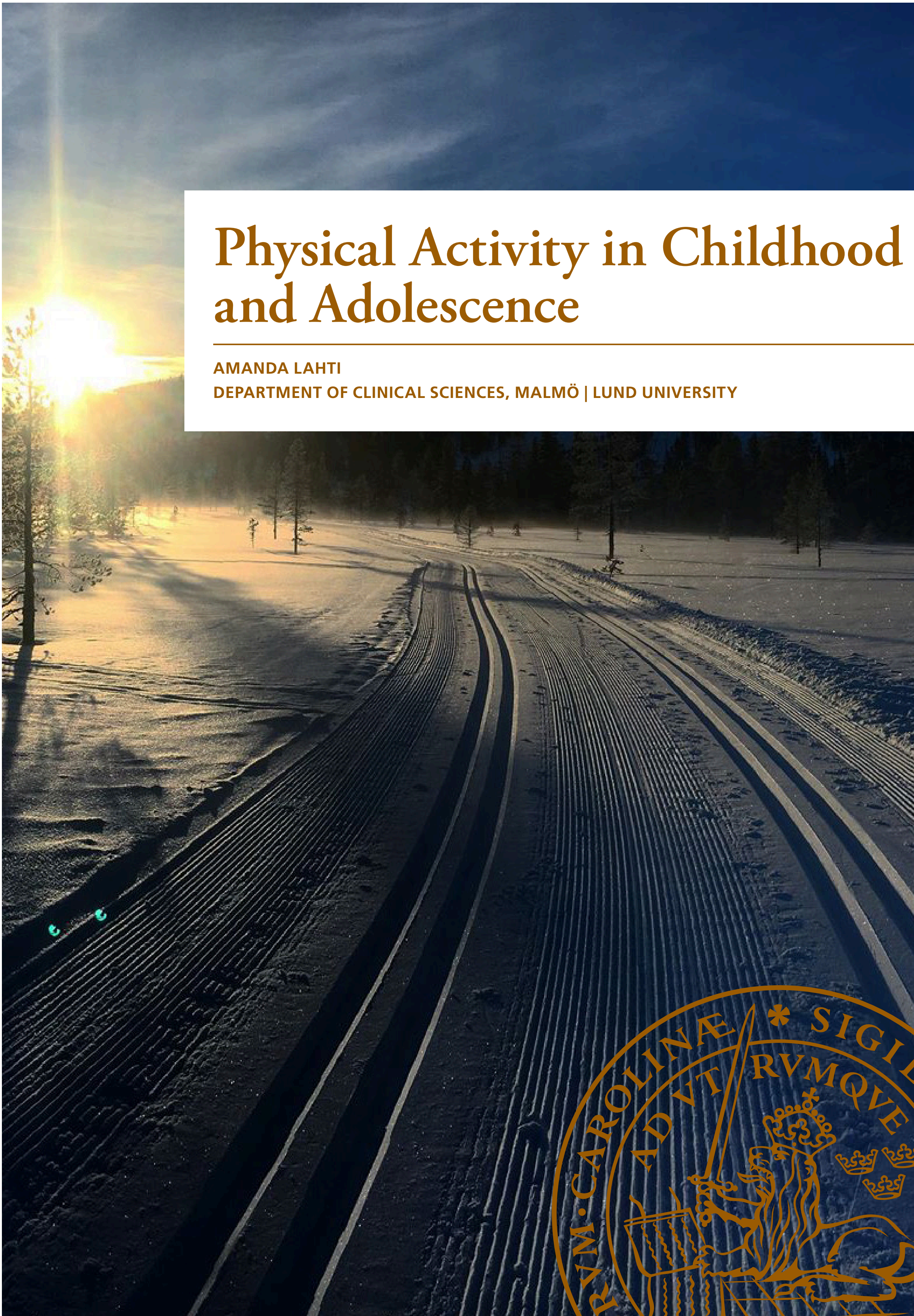

Physical Activity in Childhood and Adolescence

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Physical Activity in Childhood and Adolescence

Amanda Lahti

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DOCTORAL DISSERTATION

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Abstract

Background: Physical activity (PA) is associated with several health benefits whereas inactivity is associated with diseases. Yet, only 10-20% of Swedish children aged 11-15 years meet the World Health Organizations recommendation of minimum 60 minutes (min) of PA/day. A public health priority is therefore to promote childhood PA.

Aims: We aim to assess whether a daily school-based PA intervention is associated with higher duration of PA and/or differences in sedentary activity also after the intervention is terminated. We also aim to examine which socio-ecological factor(s) are independently associated with level of PA in eight and ten-year-old children, and if any factor(s) at age eight years are associated with lower PA levels two years later.

Methods: The osteoporosis prevention (POP) study is a population-based prospective controlled school PA intervention study that started in 1999–2000 in the city of Malmö, Sweden. The POP study includes one intervention school and three control schools. At baseline, all children (age range 6–8 years) who started first or second grade in the four schools were invited to participate. The intervention included 40 min of PA/school day during all nine compulsory school years. The control schools continued with the Swedish standard of 60 min of PA/week (1–2 lessons/week). The children and their parents were annually evaluated with questionnaires (including questions on lifestyle, PA and sedentary activity), anthropometric measurements and physical performance tests. PA was annually evaluated with a questionnaire until grade nine in compulsory school and in grade three in upper secondary school. Two years after baseline we measured PA with accelerometers. At baseline, the parents answered one part of the questionnaire regarding lifestyle factors.

Results: Three years after termination of the program, the intervention group spent 2.7 (0.8, 4.7) (mean (95% CI) hours/week more on PA and -3.9 (-9.7, 1.7) hours/week on sedentary activities compared to controls. In eight-year-old children, female sex, younger age, lower parental duration of PA, living without sibling active in a sports association and not having a parent who considered PA important, were factors independently associated with lower duration of PA. In ten-year-old children, female sex, lower body height, older age and having 60 min school-PA/week (control schools) compared to daily 40 min school-PA (intervention school) were factors independently associated with lower objectively measured PA. Finally, in eight-year-old children, female sex, lower body height, higher body mass index (BMI) and having school-PA 60 min/week (control) versus 40 min/day (intervention), was associated with lower duration of PA two years later.

Conclusions: This thesis infers that a daily school PA intervention throughout compulsory school could be a feasible strategy to increase childhood PA, not only during, but also beyond termination of the program. This conclusion is strengthened by our finding that the intervention program in ten-year-old children was associated with higher level of objectively measured PA regardless of a variety of socio-ecological factors. In addition, in eight-year old children female sex, shorter body height and higher BMI are factors associated with lower PA levels two years later. We therefore speculate that the first compulsory school health examination could use these estimates to identify children on a population-based level at risk of developing lower level of PA, thereby enabling timely PA interventions to be instituted.

Key words: Children, Socio-ecology, Physical Education, Socio-ecological model

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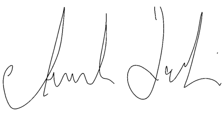
Signature  Date 2019-08-26

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Dedicated to my beloved family, Wictor, Wilton and Ingvild

"Allt kan man ta ifrån människan. Utom en sak- den yttersta friheten att välja förhållningssätt till det som livet för med sig"

Table of Contents

Abbreviations

95% CI	95% confidence interval
ANCOVA	Analysis of covariance
BMI	Body mass index
CI	Confidence interval
DXA	Dual-energy X-ray absorptiometry
GPA	General Physical Activity
Kcal	Kilocalorie
METs	Metabolic Equivalents
MPA	Moderate Physical Activity
MVPA	Moderate and Vigorous Physical Activity
PA	Physical activity
PBM	Peak Bone Mass
PE	Physical education
POP	Paediatric Osteoporosis Prevention (study)
PT	Peak Torque
RAE	Relative Age Effect
SD	Standard deviation
Sec	Second
SEMs	Socio-Ecological Models
VPA	Vigorous Physical Activity
WHO	World Health Organization

Glossary

Accelerometer	Device that measures physical activity by recording acceleration of bodily movement
Accuracy	How well a measured value corresponds to the true value
Adolescents	WHO defines adolescents as individuals aged 10–19 years
Children	According to WHO, a child is a person aged 19 years or younger unless national law defines a person to be an adult at an earlier age (in Sweden at 18 years of age)
Exercise or training	PA that is planned and structured with repetitive bodily movement performed to improve or maintain one or more components of physical fitness
Female Athlete Triad	A syndrome of disordered eating, amenorrhea and osteoporosis
Metabolic Equivalents	One metabolic equivalent corresponds to the level of energy expenditure while resting quietly, mostly corresponding to 3.5 ml O2/kg/min
Moderate Physical Activity	PA performed with accelerometer measurements above 3500 counts per minute (e.g., brisk walking)
Morbidity	The amount of disease within a population
Mortality	Numbers of deaths per year per 1000 persons
Muscle strength	Amount of force that can be produced by a muscle in a single contraction
Peak Bone Mass	The highest amount of bone mass that a person reaches in life
Peak torque	Maximum force applied around a pivot point
Physical activity	Any bodily movement produced by the contraction of skeletal muscles that result in energy expenditure
Physical fitness	The capacity of the heart, blood vessels, lungs, and muscles to function at optimum efficiency and to carry out daily activities without undue fatigue.

Precision	Refers to how close estimates from different samples are to each other
Pre-pubertal children	Children in Tanner stage 1 or 2
Relative-Age Effect	Refers to the fact that children born at the beginning of the year are physically and mentally more mature than those born at the end of the year and therefore hold advantages regarding PA and school performance
Reliability	Refers to the consistency of measurements
Sedentary behavior	Time spent in front of different screens
Self-efficacy	The individual's belief in his/her intrinsic ability to achieve goals and control his/her own life
Socio-Ecological Models	Theoretical models which recognize that factors across several domains interrelate to determine children's physical activity levels, and that no single factor alone can account for children's behavior
Tanner	A scale with five steps of physical development in children and adolescents based on primary and secondary sex characteristics
Tracking	Refers to behaviors that follow individuals and traits over time
Validity	The extent to which an instrument or method actually measures what it is intended to measure
Vigorous Physical Activity	PA performed with accelerometer measurements above 6000 counts/minute (e.g., running)

Original Papers

I. **Long-term effects of daily physical education throughout compulsory school on duration of physical activity in young adulthood: an 11-year prospective controlled study.**

   Lahti A, Rosengren BE, Nilsson J-Å, Karlsson C, Karlsson MK.

   BMJ Open Sport Exerc Med. 2018 Apr 10;4(1):e000360. doi: 10.1136/bmjsem-2018-000360. eCollection 2018

II. **Association between Biological Social and Environmental Factors and Duration of Physical Activity in Eight-Year-Old Children**

   Lahti A, Rosengren BE, Nilsson J-Å, Peterson T, Karlsson MK.

   Acta Paediatr. 2019 Mar 9. doi: 10.1111/apa.14776. [Epub ahead of print]

III. **Biological, Social and Environmental Associations of Objectively Measured Physical Activity in 8 to 11 Year-Old Children**

   Lahti A, Rosengren BE, Dencker M, Nilsson J-Å, Karlsson MK. Submitted to Scand J of Med and Sci in Sports

IV. **Is it Possible to Identify Children at Risk to Develop Low Level of Physical Activity? – A 2-Year Prospective Study**

   Lahti A, Rosengren BE, Dencker M, Nilsson J-Å, Karlsson MK. Submitted BMJ Open Sport Exerc Med.

Introduction

Physical Activity

For thousands of years, humans have depended on the ability to be physically active when hunting or being hunted for survival. In that way, physical activity (PA) has been a natural part of our everyday life. In modern time, machines have taken over many tasks that used to be performed physically by man, and technical devices such as smartphones, computers and iPads have brought new challenges to prevent inactivity and related diseases. In 2018, the World Health Organization (WHO) estimated inactivity as the fourth leading cause of death (after high blood pressure, tobacco use and high blood glucose)[1] and to be responsible for a substantial economic burden[2]. In addition, one study including 168 countries and 1.9 million adult study-participants estimated that more than a quarter of the global population is insufficiently physically active[3]. This trend is also found in a global cohort of 11-17 year-old children where only one fifth meet the WHOs recommendation of 60 minutes (min) of moderate and vigorous physical activity (MVPA) per day[4]. Unfortunately, there has been a secular trend in PA levels and cardiovascular fitness among both children and adults during the last centuries[5,6] and inactivity related-diseases are expected to rise[7]. As PA habits also often track from childhood into adulthood[8,9], it should be a public health priority to promote PA and establish a healthy lifestyle in young years.

Definitions of Physical Activity, Inactivity and Sedentary Behavior

PA is defined as *"any bodily movement produced by skeletal muscles that requires energy expenditure"*[10]. This means that PA can be undertaken in many different ways, such as organized PA activities (e.g., handball and football), but also as transport (e.g., cycling and walking) and part of domestic tasks (e.g., cleaning and carrying). Exercise and/or training refers to a subset of PA that is planned and structured to maintain or improve physical fitness[10].

PA can be performed at different intensities and is usually divided into moderate (e.g., brisk walking) and vigorous (e.g., running) intensity[11] and can be expressed in terms of their metabolic equivalents (METs)[12]. 1 MET is defined as energy expenditure when sitting, and is equal to 3.5 millilitre oxygen per kilo body weight min (equivalent to 1.2 kcal per min for a 70 kg person)[10,11]. Further, 2 METs requires twice the resting metabolism and 3 METs three times the resting metabolism and so on[12]. Previous studies including 8-11 year old children have defined moderate PA as 3-6 METs and vigorous PA as > 6 METs[13,14].

The term inactive is commonly used to describe those who do not meet specified PA guidelines[10,11]. Sedentary activity or sedentariness is often defined as an energy expenditure of ≤1.5 metabolic equivalents (METs), which mostly occurs in a sitting or reclining posture[10,11]. PA and sedentary activity are two behaviors that are not opposite of each other as it is possible to meet specific PA recommendations but also devote several hours to sedentary activity. In other words, children can be classified as both physically active and sedentary. This is of importance as sedentary activity is, independent of PA, a major mortality risk factor[15].

Figure 1. A very physically active child.

Health Benefits of Physical Activity in Children

The health benefits of a physically active lifestyle are well-established[16]. Children aged 5-17 years are recommended to spend 60 min on MVPA per day[17] and the dose-response evidence from several studies infer that more PA will be even better[16,18]. The following paragraphs focus on different health benefits of PA in children.

Cardiovascular Health

In 2016, cardiovascular diseases accounted for 17.6 million of deaths globally, making it the leading cause of non-communicable disease mortality[19]. The cardiovascular diseases are commonly a concern in adulthood but cardiovascular risk factors are often present already in childhood and can predict cardiac pathology, morbidity and mortality later in life[20]. As it is difficult to achieve sustainable lifestyle changes in adulthood, it is desirable to establish good cardiovascular health already in childhood.

PA intervention studies including relatively small sample sizes of children with high blood pressure and/or obesity found significant reductions in systolic and diastolic blood pressure in response to aerobic exercise training[21,22]. One of these cited studies also found reduced insulin levels, independent of measureable changes in body composition[21]. Another cross-sectional study including 3,110 children aged 12-19 years found that children with worse cardiorespiratory fitness (measured with a submaximal treadmill test) were more likely to have hypercholesterolemia than those with better cardiorespiratory fitness in both sexes[23].

Overweight and Obesity

The prevalence of overweight and obesity in children has increased significantly all across the world during the last three decades[24]. This trend is also observed in Swedish children where approximately one in five children are overweight, including 3% obese[25]. Overweight and obesity in childhood increase the risk of developing cardiovascular diseases later in life regardless of BMI in adult ages[26]. BMI often track from childhood to young adulthood[27]. One Norwegian study reported that six out of ten children who were overweight/obese at age 5-7 years were also overweight/obese at age 15-17 years[28], with similar proportions found in a Swedish cohort of children[29]. Prevention is therefore of highest importance regarding childhood overweight and obesity. Together with a healthy diet[30] and reduction of sedentary activities[31], PA is a modifiable key component in reaching and maintaining a healthy body weight[30,31].

Bone Mass and Fracture Risk

Regular PA can contribute to strong bones[32-36]. Peak bone mass (PBM) is defined as the maximal bone mass an individual attains during the lifespan, usually reached in early adulthood at the end of the skeletal maturation[33]. This typically occurs in the early 20s in females and late 20s in males[32]. Theoretical analysis support the important role of PBM in future fracture risk, and hypothetical calculations infer that a 10% increase of PBM can postpone the development of osteoporosis by 13 years[34]. PMB is also an important determinant of bone mineral density (BMD) and fracture risk later in life[34]. In addition, studies of elite athletes indicate that induced high BMD by regular PA in young years is partly preserved in adulthood and accompanied by lower fracture incidence than in aged-matched controls[34-36]. This supports that regular PA in childhood are of importance for bone mass and fracture risk later in life.

Mental Health

According to a report presented every four years by the Swedish Health Institute, there has been an increase in insomnia, nervousness, irritability and sense of depression among Swedish 11–15-year-old schoolchildren from 1985/86 until 2017/18[37]. In one large meta-analysis including 127,714 children aged 5-17 years, the researchers found a dose-response connection between depression and sitting more than two hours/day[38]. Regular PA is also known to decrease the risk of anxiety[39] and depression[40] and to improve self-efficacy[41].

Academic Performance

In recent decades, the proportion of children eligible for upper secondary school (Swedish: gymnasiet) in Sweden has decreased[42,43]. The proportion of eligible students was only 86% in 2015, the lowest proportion since 1998[42]. This trend is not unique to Sweden, as school results have declined in several countries during the last few years[43]. In a previous report from the paediatric osteoporosis prevention (POP)-study, an intervention with daily 40 min scheduled school-PA was associated with higher proportions of pupils being eligible for upper secondary school compared to controls receiving 60 min of school-PA/week[44]. The association between higher duration of school-based PA and improved academic performance has been verified in other studies[45-47]. Mechanisms to explain this phenomenon could possibly be due to increased blood flow and higher oxygen content to the brain[48], increased levels of endorphins resulting in stress reduction[49] and increased growth factors that could help create new nerve cells and support synaptic plasticity[50]. Overall, PA contributes to good academic performance in school-aged children.

Possible Adverse Effects of Physical Activity

The benefits of an active lifestyle are well-established in the literature[16,18], but it is also important to consider whether PA may have adverse health effects. The following paragraphs focus on different adverse effects of PA in children.

Paediatric Sport-related Fractures, Injuries and Trauma

It is conceivable to think that physically active children have a higher injury risk due to higher exposure to trauma and overload, compared to inactive children. In Sweden, approximately 40,000 children aged 0–17 years (with a top in the age range 13–15 years) are annually estimated to visit the emergency department due to sport-related injuries, corresponding to more than a fourth of all visits to the children's emergency department[51]. In addition, 36,000 Swedish children visit the emergency department due to injuries occurring during school-time[52]. Concussions[53] and anterior cruciate ligament injuries[54] represent common, and sometimes serious paediatric sport injuries that can have long-term implications.

A previous report from the POP-study found an increased fracture risk after one year with an intervention of 40 min school-PA in schoolchildren[55]. However, after the first year, the relative fracture risk declined with each year of daily school PA so that the fracture risk after seven years with the intervention was halved compared to what was expected by age[55]. In addition, another study that examined 9-12-year-old Swedish schoolchildren found a higher risk of sports injuries among children with low habitual PA levels compared with the most physically active ones[56]. Taken together, sports injuries may be more common among youth elite athletes but in population-based cohorts of schoolchildren, more physically active individuals often face lower injury risk than the least physically active ones.

Figure 2. A child exposed to trauma during fotball.

Female Athlete Triad

The female athlete triad refers to a syndrome of three components: disordered eating, amenorrhea and osteoporosis[57]. The triad was implied in studies from the 1980s, that found a relationship between eating disorders (energy deficit) menstrual dysfunction[58] and low BMD[58,59]. Several factors may contribute to the development of the triad, such as trying to increase sport-performance by achieving low body weight (e.g., long-distance running where body weight affect performance) or insufficient energy intake compared to energy loss during exercise. This phenomenon is mostly represented by young female elite athletes[57] (with an ongoing debate about the existence of a male athlete triad[60]) and may not be an overwhelming problem among non-elite school children.

Inferior Academic School Results

Opponents of daily scheduled PA in school have put forward concerns as to whether other academic subjects will be overridden by additional scheduled PA. This argument has been negated by a thesis from the POP-study that found an association between daily scheduled 40 min PA per day and higher academic achievements, compared to the results in children with 60 min PA per week[44].

Psychological Aspects

Opponents of school-based PA programs also have concerns that some children dislike PA and feel vulnerable during physical education (PE) classes. One interview study including 6,788 Swedish children in grade nine at 16 Swedish compulsory schools revealed that the majority of children enjoyed PE classes, but 14% felt uncomfortable changing clothes in front of other children, 11% felt clumsy during class, 8% felt left out and 5% even felt that PE classes worsened their body image and lowered their self-esteem[61]. Some opponents therefore raise the question if it is fair to force children who are not comfortable in PE classes to partake in mandatory daily school PA. On the other hand, if we cannot force children who dislike PE to take part in PE classes, can we then force them to take part in Math, English or any other subject that they may dislike? In addition, at baseline of the POP study, 306/314 (98%) who replied to the question *"Do you enjoy physical education classes (yes/no)?"* answered "yes", which may infer that children in these ages actually enjoy being physically active.

Recommendations of Physical Activity and Sedentary Activity

Physical Activity

Due to the wide range of health benefits that follow a physically active lifestyle, and the increased risk of developing disease if not being physically active enough, the WHO has developed global recommendations on PA for different age-groups (Table 1)[17]. According to these recommendations, children aged 5–17-years should accumulate at least daily 60 min of MVPA[17]. The WHO also states that more than 60 min daily MVPA will provide additional health benefits and that the activity should be mainly aerobic but also include activities that strengthen muscle and bone at least three times per week[17]. However, only 10-20 percent of Swedish 11-15-year-old children meet this recommendation[37], with a similar proportion found in a global cohort of children[4].

Table 1.
Summary of the World Health Organization's (WHOs) recommendations of physical activity (PA)

Age	Recommendation
< 1 year	Be physically active several times a day through interatvie floor-based play and more is better. For those not yet mobile, this includes a minimum 30 min in prone position spread throughout the day while awake.
1-2 years	Spend a minimum of 180 min on different physical activities at any intensity spread throughout the day and more is better.
3-4 years	Spend at least 180 min on different types of PA at any intensity of which at least 60 min is MVPA spread troughout the day. More PA is even better.
5-17 years	60 min of MVPA per day. Most of the PA should be aerobic. Vigorous-intensity activities should be incorporated, including those that strengthen muscle and bone at least three times per week.
18-64 years	150 min of moderate or 75 min of vigorous PA per week, including muscle strenghtning activities on two or more days per week.
65+ years	150 min of moderate or 75 min of vigorous PA per week, including muscle strenghtning activities on two or more days per week, and also balance enhancing and fall-preventing activities on three or more days per week.

Sedentary Activity

In recent decades, scientists have become more interested in sedentary activity and physical inactivity, as an independent risk factor for developing clinical disease, regardless of additional PA levels[15,62-64]. The core of these studies is that being sufficiently physically active may not compensate for the adverse health effects of time spent sedentary. Despite research in progress, we still know little about the detrimental health effects of sedentary activities and no consensus guidelines exist on limiting sedentary behavior. There is probably a need to develop such guidelines as one study including 5,844 children aged 9-11 years from different countries all across the world found that children spend mean nine hours per day on sedentary activity[65]. Screen time is the most common sedentary behavior in children and accounting for approximately 40% of all sedentary activity[65]. According to one report including 10 countries and 27,637 participants, the proportion of children using a computer for two hours or more per day showed a steep increase between 2002 and 2014 across all countries from 15-35% to 65-70%, especially among 11-13-year-old children during the onset of puberty[66]. In Sweden, a third of all children aged 13-15 years spend more than four hours/day in front of different screens[67]. Canada[68], the United Kingdom[69] and Australia[70] are some countries that published official sedentary behavior public health guidelines (Table 2). These recommendations differ between countries and have been criticized due to limited number of evidence-based studies that underlie the guidelines[71]. In 2019, the WHO released sedentary guidelines for children under five years of age[72], but corresponding guidelines for older children and adolescents do yet not exist.

Figure 3. Screen time activity in children.

Table 2.
Recommendations regarding sedentary activity in children among different countries.

Country	Age	Recommendation	Reference
Australia	0-5 years	Should not be restrained for more than 1 hour at a time (e.g. in a stroller, car seat or high chair). Children < 1 year should not spend any time watching television or using other electronic media. For those aged 2-5 years, screen time should be no more than one hour in total throughout the 24-hour period- less is better.	Australian Government, department of health[70]
	5-17 years	Minimize the time they spend being sedentary every day by limiting use of electronic media for entertainment to no more than two hours a day - lower levels are associated with reduced health risks. Break up long periods of sitting as often as possible.	
Canada	0-2 years	For those under two years, screen time is not recommended.	Canadian Society for Exercise Physiology[68]
	2-4 years	For children two to four years, screen time should be limited to one hour per day; less is better.	
	5-17 years	No more than two hours per day of recreational screen time; Limited sitting for extended periods.	
Sweden	0-18 years	No current national recommendation to limit sedentary activity exists.	Physical Activity in the Prevention and Treatment of Disease (FYSS) [Swedish: Fysisk aktivitet i Sjukdomsprevention och Sjukdomsbehandling][73]
United Kingdom	0-18 years	All children and young people should minimize the amount of time spent being sedentary (sitting) for extended periods.	Department of Health, Physical Activity, Health Improvement and Protection[69]

Measuring Physical Activity

Measuring PA levels is challenging for many reasons. Unlike adults, PA patterns in children are characterized by intense, short and sporadic bursts of PA, rather than occurring in continuous time periods[74]. PA in children is also characterized by playing and running to and from different spots[74,75], which makes it difficult for both children and parents to report PA with accuracy. Currently, no gold standard exists for choosing method to measure PA in children and each alternative has its strengths and limitations[76-78].

A variety of methods to assess PA behaviors in children exists, including self-reported measures such as questionnaires, logs, diaries and direct observations[76-78]. Self-reported measurements have the advantage of being cheap and easy to administer[79,80]. It is also a strength that self-estimated duration of organized leisure time PA associate with objectively measured general PA (GPA)[81]. The disadvantages of self-reported measurements are that they are likely to be biased as they rely on subjective experience[80]. It is also difficult to estimate PA at moderate intensity (e.g., walking in stairs, brisk walking) as it is easy to forget to report activities at this intensity[79,80].

There are also objective methods, such as accelerometers, pedometers and heart-rate monitors that measure PA[77]. An accelerometer is a small device that operates by measuring acceleration along a given axis. Accelerometers have the advantage of computing both PA duration and intensity and to capturing large amounts of data[82]. The accelerometer converts bodily movement info electric signals (counts) that are proportional to the muscular force that produce the motion[83]. The counts are summarized over a specific time period called an epoch which normally variates between 10 and 60 seconds (sec). The use of 60 sec epochs may be inappropriate due to the spontaneous and intermittent PA pattern in children[74,75] and may result in underestimation of MVPA. Therefore, shorter time epochs (i.e., 5-15 sec) are recommended for children[84]. However, shorter epochs require larger data storing capacity and reduce the number of days that PA can be measured[83]. The first accelerometer studies used equipment that was only capable of storing data using epoch lengths of 60 sec and could only measure PA for three to four days[83]. Today it is possible to assess up to 30 days, but a minimum of seven days of recording is often considered enough[85].

The disadvantages of accelerometers are that they are not water resistant and may underestimate PA performed in water (e.g., swimming) and activities with almost no vertical acceleration (e.g., cycling)[82]. Accelerometers are also more expensive than questionnaires and require technical equipment to analyze the collected data[82]. Even more, there is no standard protocol for choosing cut-off points for the different PA intensities which makes it difficult to compare PA levels between studies[86-89].

Pedometers are another example of a device for measuring PA. They have the advantages of being cheaper than accelerometer but have the disadvantage of not being able to give information about the duration or intensity of PA (only steps taken during a selected period of time)[90]. Heart-rate monitors are another method which is reliable on PA duration, frequency and intensity[90]. They are also easy to wear and can be used for long periods with low efforts. However, heart-rate also varies with emotional state, anxiety and level of fitness[90]. The rapid technical development has also made it possible to measure PA by the use of smartphones[91], but more knowledge is needed on the strengths and limitations of using such technical device as measurement and intervention tool.

Figure 4. A child wearing the MTI acceleromter model 7164 that was used in the POP-study

Are Physical Activity Levels in Children Modifiable?

In 1998, Rowland et al. presented the Activity Stat Theory as a potential intrinsic, biological set point for PA levels[92]. The theory suggests that PA levels are non-modifiable and set at an intrinsic individual level[93,94], similarly to the homeostatic mechanism in which internal body temperature is regulated to the set point of approximately 37 °C[95]. The Activity Stat Theory has been used to explain why some interventions have failed to increase PA in both humans and animals[96-99]. According to the theory, an increase of PA during one part of the day would be compensated with a decline in PA during another part of the day (Figure 5)[92-94]. In other words, according to the theory, an increase in PA during school-time would be compensated with a decline in PA during leisure-time, to maintain a similar total level of PA. However, the Activity Stat Theory has been opposed by several studies that have succeeded in increasing PA in children, both short- and long-term[100,101]. Previous research from the POP study shows that children with daily school PA are not only more physically active than controls during school time, but are also involved in more PA during leisure time[101]. One systematic reviews also state that the Activity Stat Theory is inconclusive[93]. Taken together, it seems likely that it is possible to modify PA levels in children.

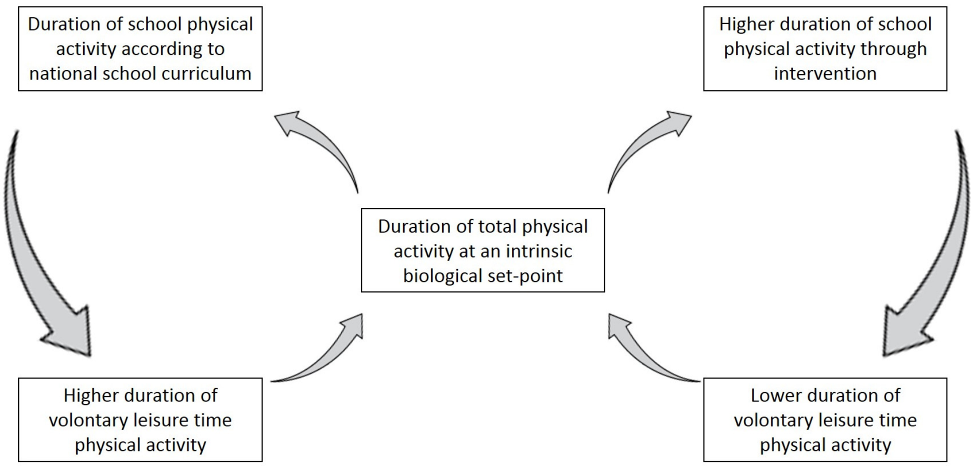

Figure 5. Illustration of the Activity Stat Theory.

The Gap between the Most and Least Physically Active Children

In Sweden, there is a growing span between the proportions of children who are highly active and those who are inactive[102-104], a phenomenon also observed in other Nordic countries[104]. According to one Swedish report, one fifth of children aged 12-15 years are not physically active at all during leisure time (predominantly girls), while the same proportion of children (predominantly boys) are highly physically active after school[103]. The same phenomenon, where some children always participate whereas some consistently choose not to participate, is observed in Swedish school PE lessons[103].

In addition, a recent report including almost a thousand Swedish 15-year-olds shows that less than one third of children with parents without post-secondary degree and with low income participate in organized leisure time, as opposed to four fifths of children with parents with post-secondary degree and high income[105]. The core of this report was that there is a socio-economic difference in participation rate in organized leisure time PA in advantage for children of Swedish origin, living in wealthy communities/families and having well-educated parents and that higher costs for organized leisure time PA exclude children without these social advantages.

However, it is important to remember that PA can be undertaken in many different ways[10,11] and one study shows that children in poorer areas are just as physically active as children living in more privileged areas[106]. Results from other studies only focusing on expensive organized leisure time PA may thus have been biased. In a public health perspective, it is of interest to identify the least physically active children (who probably are of highest risk of developing inactivity-related diseases), so that actions can take place in time, preferably before inactivity occurs.

Yet, we lack knowledge on independent determinants of PA behavior in children and whether such factors could be used to identify children who will continue to have, or those who will develop low PA levels, in both a short and long-term perspective. We also lack knowledge of whether interventions targeting different factors that have been shown in cross-sectional studies to be associated with childhood PA, actually lead to higher PA levels.

Figure 6. A girl at Ängslättssklan (the intervention school) participating in a physical education class in 2019.

The Socio-Ecological Model

Urie Bronfenbrenner was a Russian-born American psychologist who is famous for his theoretical model, including micro, meso and exo environmental domains, when trying to understand how behaviours in children develop[107]. Bronfenbrenner illustrated his theory as onion layers, with each layer representing a domain close to (e.g., family) or further away (e.g., laws and policies) from the child[107]. He also stated that the behavioural development in children is shaped by the interaction between factors across all of these domains, including parents, friends, school and culture[107,108]. This theory has subsequently been developed by McLeroy et al[109] and Stokols[110] into the socio-ecological model (SEM) that intend not only to understand, but also to guide interventions aiming to change behavior on a population level. The SEM uses five hierarchical levels: individual, intrapersonal, community, organizational and policy[111] (Table 2).

Table 2.
Description of each domain of the socio-ecological model.

Domain	Description
Intrapersonal	The characteristics of an individual that affect behavior change, such as knowledge, attitude, self-efficacy, gender, age, ethnicity.
Interpersonal	Social influences that can affect an individual behavior, including family, friends, peers, siblings, religious networks, and teachers.
Organizational	Influence from schools, workplaces and other organizations.
Community	Refers to the built environment, infrastructure and facility access that influence behavior of an individual, but also natural forces such as weather conditions.
Policy	Local, national and international laws and policies, such as regulation of fees for access to government-funded recreational areas/gyms/leisure time activities, school policies and laws regarding infrastructures and societal construction.

A central conclusion of ecological models is that it takes a combination of factors at different levels to achieve substantial changes in PA levels[111]. The SEM has later been adapted to fit the PA research field (Figure 7)[111] and in this thesis, we categorize included factors into three different domains: biological, social and environmental.

A weakness of the SEM is the lack of specificity about the most important hypothesized factor to influence PA behavior in children. Furthermore, prospective controlled intervention studies with multilevel influence are difficult to design, conduct and then finally to draw the right conclusions from. As it seems impractical to target all factors within the SEM that are known to influence children's PA levels, there is a need to specify each independent factor and the relative influence of these factors.

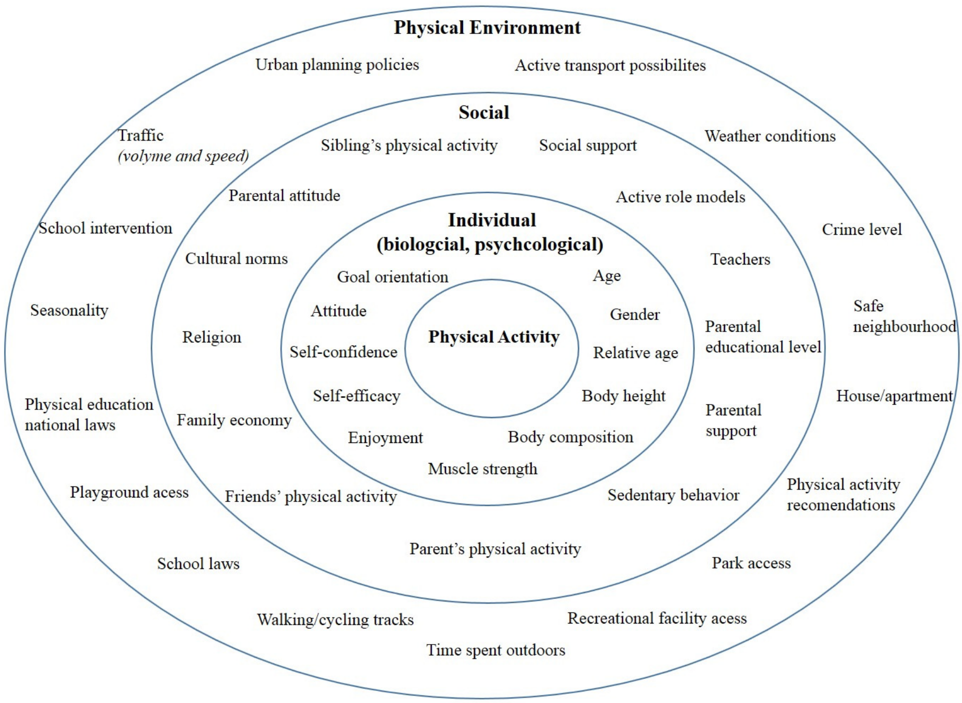

Figure 7. Levels of influence on physical activity in children and adolescents.

Socio-Ecological Factors Reported to Influence Physical Activity in Children

The following paragraphs focus on factors across biological, social and environmental domains of the SEM that has found to be associated with PA in children.

Biological factors

Age

PA levels commonly increases from birth until adolescence when PA starts to decline in both genders[66]. This decline in PA with age in adolescence is one of the most consistent findings in PA research[66,112-114], although the phenomenon is not fully understood. It is for example not known if the mechanism of this decline is biological, social and/or environmental and only few studies have attempted to determine if this decline occurs in all PA activities and intensities. The decline is steepest between ages of 13 to 18 years and is greater in girls than boys, and boys are therefore more physically active than age matched girls in pubertal ages[114]. However, more recent studies have found declines in PA levels already in younger ages and infer that this phenomenon is apparent already at seven years of age in the first grade of the compulsory school years[112,113]. Identifying ages of greatest decline in PA may be useful in targeting interventions preferable before PA habits become stable.

Sex

Boys are found to be more physically active than age-matched girls during all compulsory school-years[115] with significant differences occurring in adolescence ages[66]. Even if this sex discrepancy has been well-known for decades, only few studies have attempted to examine potential causes to this phenomenon[116]. One possible explanation is that girls experience less social support towards PA[117]. Biological differences may also contribute to sex differences in PA as the sex discrepancy in PA levels was reduced after adjusting for sexual maturity, that may be related to girls maturing at an earlier chronological age[118].

The Relative Age Effect

In most school systems and in organized leisure-time PA activities, children are grouped according to chronological age. As sport performance in children are often age-related, this division into age-groups is probably needed to ensure fair competition and chance of success for all children. But as children go through rapid cognitive, physical and emotional development, there can be large differences between the youngest and the oldest children born within the same chronological year[119]. The phenomenon where significant differences in performance are in advantage for those born at the beginning of the year, is referred to as the relative age effect (RAE)[120-126]. The RAE has predominantly been examined and identified in youth elite-sport[122,123,126] but also on a population-based level, regarding academic achievements[120], fundamental exercise skills (e.g., sprinting, throwing and jumping)[121] and in attendance of specialized sport schools[120]. The RAE may also influence PA levels in non-elite school children as children who perform better in sports may find it more enjoyable to exercise.

Figure 8. A sport sequence where physical maturation and body height may affect preformance in adolescence boys.

Social Factors

Family influences and socio-economic differences in physical activity

According to several studies, family influence plays an important role in childhood PA for many reasons. Children who experience better parental support and encouragement towards PA are often found to be more physically active than those with less support[127]. Aspects of parental support that have been associated with higher PA include parental involvement[128] and mentoring[129]. In addition, children with more physically active parents are also more likely to be physically active themselves[130], as activities are often shared between family members.

Siblings are also important influence on PA that, similarly to parents, may increase PA by co-participation and social support[131,132]. Siblings may also serve as a role model and/or supervisor in the absence of parents, thus acting as a parental influence. In addition, higher rates of obesity are found in children without siblings[133]. As obesity in children is related to lower PA and more sedentary activity[134], it may be that sibling(s) encourage more PA and less sedentary behavior. In addition, in adolescent ages when PA levels start to decline[66], children commonly spend more times with friends and siblings than parents[135] and this may lead to a greater influence on PA from friends and siblings than parents in these ages.

Figure 9. The author running together with one of her children.

Socio-economic differences in PA has also been extensively studied. Social inequalities to the disadvantage of children from families with low socio-economy are found in dietary habits[136] and obesity prevalence[137] whereas mixed results are found regarding PA levels[137,138]. What is generally agreed upon is that children with higher socio-economic status are overrepresented in organized leisure time PA and that the most difficult subgroup of children to reach is young girls in poorer areas.

The research group *Ung Livsstil (Youth lifestyle's)* have since 1985 examined almost 80,000 adolescents from different parts of Sweden, and their reports have shown that children in higher socio-economic groups are overrepresented in Swedish sport associations with the greatest difference among girls[139]. Unfortunately, since this study started in 1985, the inequalities in organized leisure PA based on socio-economic background has even increased in Stockholm and other Swedish cities[139]. The advantages of having well-educated and wealthy parents could possibly include better possibilities to pay for expensive leisure-time activities and that higher education may lead to better awareness of PA induced health benefits. They may also experience better access to PA facilities[140], green parks[140,141] and have lower crime-levels in their community[140], and thereby have better environmental possibilities for PA than children living in poorer areas. Others have found that children with parents of higher educational level[142], having physically active family members[142,143] are more physically active than children without these attributes. In addition, children living with two parents instead of single households are also known to involve with more organized leisure-time PA[144].

In contrast, one study found that children living in low-income families engaged in more PA, had better parental support for PA and that their parents more often sent their children outside to play, than children living in families with higher income levels[138]. This means that children from less deprived areas may involve with PA in other ways than through organized leisure time PA.

Taken together, PA levels in children across socio-economic groups may not vary as much as dietary habits and obesity prevalence, and study results might be biased if they only focus on PA undertaken during expensive organized leisure time physical activities. However, this may not be a problem when comparing PA levels among children within similar socio-economic settings and self-estimated organized leisure time PA has actually been shown to be associated with objectively measured GPA[81].

Environmental Factors

School-Environment

Schools have been suggested to be a feasible arena to promote PA as almost all children in society spend a large proportion of their waking hours in school[145]. Schools therefore provide the opportunity to reach almost all children in the society, including those that do not already have an interest in sport or have parents who encourage leisure-time PA activities. In addition, many school-based PA interventions have shown promising short and long-term health benefits regarding PA behavior [97,100,101,146,147].

Despite the worrying numbers of inactive children[4,37], there has been a reduction in PE classes in Swedish schools in favour of academic subjects during the last century[148,149]. PE was introduced in Swedish schools in the late nineteenth century as a daily subject[149]. Thereafter, the amount of PE in compulsory Swedish schools has progressively been reduced to a mean of 60 min/week provided in 1–2 lessons in 2007, corresponding to 500 hours of PE throughout compulsory school. This decline in PE given in the Swedish compulsory school has been a topic of ongoing debate in Swedish society during the last decade and during autumn 2019, the PE hours in the Swedish compulsory schools will be increased from 500 to 600 hours throughout compulsory school[148].

Previous studies, which have examined the effect of increased school-based PA, have often been short-term[101,146,150-152] and few examine whether sustained effects are retained after termination of the program[147,153-156]. More research is therefore needed to evaluate possible prolonged effects of school-based interventions and whether it is possible to teach children the habit of an active lifestyle that track into adulthood. If so, school-based PA interventions could perhaps be a feasible strategy to prevent inactivity and related diseases later in life.

Figure 10. Children participating in a physical education class at Ängslättsskolan (the intervention school).

Aims of the thesis

Paper I

To evaluate whether a 40 min daily school-PA intervention during the nine compulsory school years is followed by higher duration of self-estimated PA and/or less sedentary activity three years beyond termination of the program.

Paper II

At school start, before the PA intervention is initiated, to evaluate whether any socio-ecological factor(s) are independently associated with subjective estimate duration of PA in mean eight-year-old (range 6-9 years) children.

Paper III

After two years with the school PA intervention, to evaluate whether any socio-ecological factors are independently associated with objective measured level of PA in mean 10-year-old (range 8–11) children.

Paper IV

At school start, before the PA intervention is initiated, to evaluate whether any socio-ecological factors in mean eight-year-old children (range 6–9) associate with lower objectively measured PA levels a mean two years later.

Hypotheses

Paper I

A daily 40 min school-based PA program during the nine compulsory school years is associated with more PA and similar sedentary activity three years after termination of the intervention comparison with 60 min school PA per week.

Paper II

In mean eight-year-old children, family influences are independently associated with duration of self-reported organized leisure-time PA.

Paper III

In mean 10-year-old children, a 40 min daily school PA intervention is independently associated with more objectively measured level of PA compared to 60 min school PA per week.

Paper IV

Allocation to 40 min daily school PA (in comparison to 60 min per week) at mean age eight-years is associated with a higher level of PA two years later.

Material and Methods

The Paediatric Osteoporosis Prevention (POP) Study

The paediatric Osteoporosis Prevention (POP) study is a population-based prospective controlled intervention study in Malmö/Sweden that started during 1999-2000, with the overall aim of evaluating the effect of daily school-based PA on a variety of health-related outcomes.

Four community-based government-funded schools located in the same geographic area were invited and agreed to participate. At baseline, all schools followed the same national Swedish standard school curriculum of 60 min PA/week, given in one to two lessons/week. The intervention school (Ängslättsskolan) increased duration of PA to 40 min per school day (200 min/week). The three remaining schools (Ribbersborgsskolan, Fridhemsskolan and Mellanheds-/Slottstadens skola) continued with the Swedish standard.

The intervention included activities within the regular school-curriculum such as ballgames and athletics. All children followed the national curriculum in all other school subjects. To increase the duration of PA, the intervention school used selectable hours called "the student's choice" (elevens val), took some time from other subjects (esthetics, music, domestic subjects) and also extended the school day. The intervention school never cut-down on core-subjects (i.e., Math, English or Swedish). No additional PA was provided during school holidays or weekends. The intervention required no extra teachers or economic resources. All scheduled PA was mandatory, even though participation in the POP study and attendance of the annual evaluations were voluntary.

Ethics

Before study start, the POP study was approved by the Ethics Committee of Lund University, Sweden (LU 453-98; September 15, 1998) and it has been conducted according to the Declaration of Helsinki. The POP study was also registered as a clinical trial (ClinicalTrials.gov. NCT 00633828). Before the study start we obtained informed written consent from parents of all participating children. All data have been analysed on group level and patient information has been anonymized.

Participating children annually underwent a DXA scan to evaluate bone mass, lean mass and fat mass that exposes the children to negligible doses of radiation. Possible adverse effects of PA in schoolchildren are discussed in a previous section (e.g., injury risk, anxiety related to dressing rooms and PE lessons) that also must be taken into ethical considerations regarding the POP study.

Figure 11. Picture of the intervention school (Ängslättsskolan) in the POP-study.

Study Subjects

The study population in this thesis was recruited from the POP study. All children in the four schools starting first or second grade at study start in 1999–2000 were invited to participate. Of the 564 invited children, 349 (62%) agreed to participate. From those who participated at the baseline visit, we excluded two children due to medical conditions affecting their ability to be physically active and seven children due to incomplete baseline measurements, leaving 341 children (mean age 7.7±0.6 years) (range 6–9 years) with valid baseline measurements. This cohort was followed annually throughout compulsory school (nine years in Sweden) and a mean three years beyond termination of the intervention. A total 124 (36%) of the children attended the follow-up visit three years after termination of the intervention, when they were 18.7±0.3 years (range 17–19 years). There were different numbers of children participating in each annual exam, rendering different numbers in the different studies in this thesis, with more drop-outs with longer follow-up duration. At baseline, a previous drop-out analysis found no differences in baseline age, weight or BMI between children who agreed to participate in the POP study and those who declined participation[13].

Figure 12. Children enjoying a physical education class at Ängslättsskolan (the intervention school) in 2019.

Paper I

In this study, we included children with a valid baseline and follow-up visit a mean three years after termination of the program (n=124). If the children did not participate in the last examination during the intervention (in grade nine), we used data from eight, seventh or sixth grade respectively, to register duration of PA in the higher classes within the compulsory school (with the intervention still ongoing). The follow-up was conducted three years later at the last year in the last grade during upper secondary school. In this specific study cohort, the follow-up was conducted mean four years later as we used data from previous years at the last examination during the intervention.

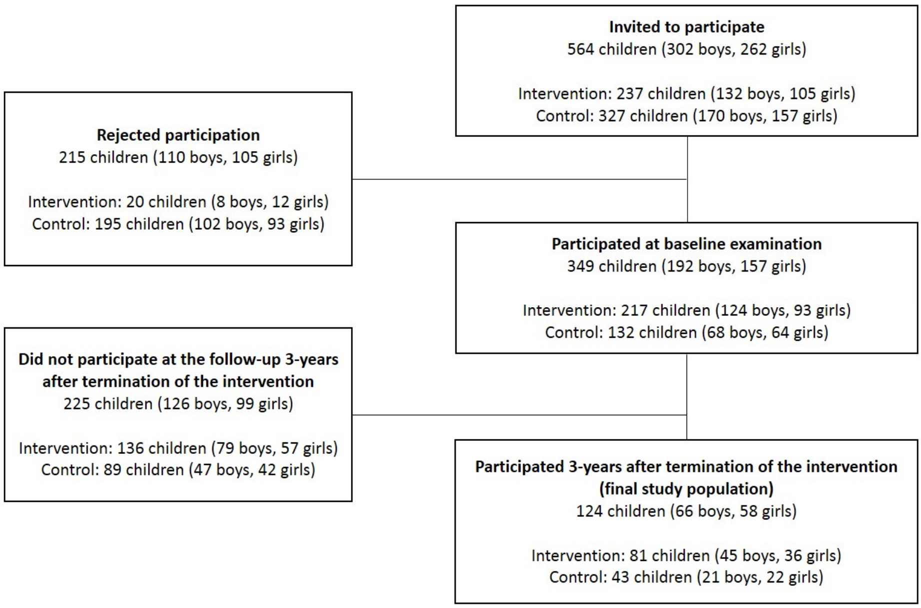

Figure 13. Flow-chart of the study-population in paper I.

Paper II

In this study, we included children with complete data on all dependent (self-estimated duration of PA) and independent factors included in the model, except for the parental attitude (i.e., having a minimum of one parent who agreed with the statement *"in our family it is important to exercise"*, compared to having no parent that totally agreed), where missing values were converted to an unknown category (n=22, 7%). From the 349 children participating at the baseline visit, 300 children (86%) were included in this study.

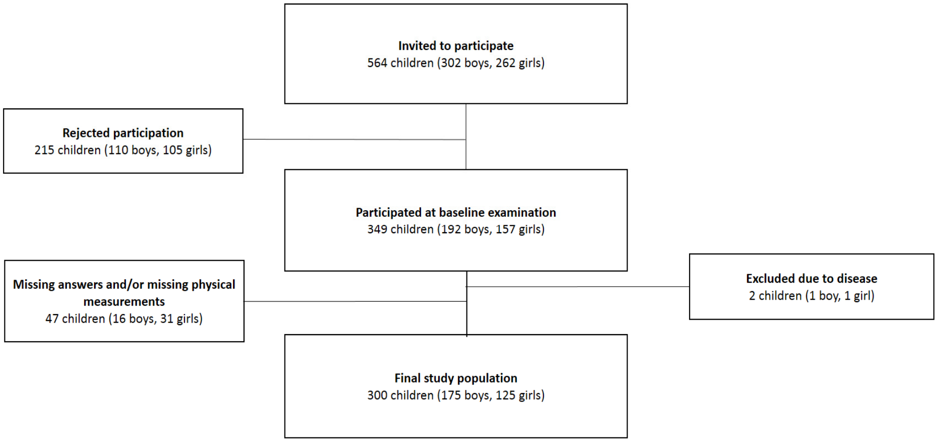

Figure 14. Flow-chart of the study-population in paper II.

Paper III

In this study, we included children with complete data on all dependent (objectively measured PA) and independent factors included in the model. An unknown category was created for missing values regarding parental attitude to PA (i.e., having a minimum of one parent who agreed with the statement "*in our family it is important to exercise*", compared to having no parent that totally agreed) (n=15, 7%), and if only one parent answered about duration of organized PA, we used this as the mean value for both parents (n=6). No other missing data imputation was made. Of the 250 children participating at the follow-up visit two years after baseline, 209 children had complete answers in the questionnaire and had conducted the physical measurements and were included in this study.

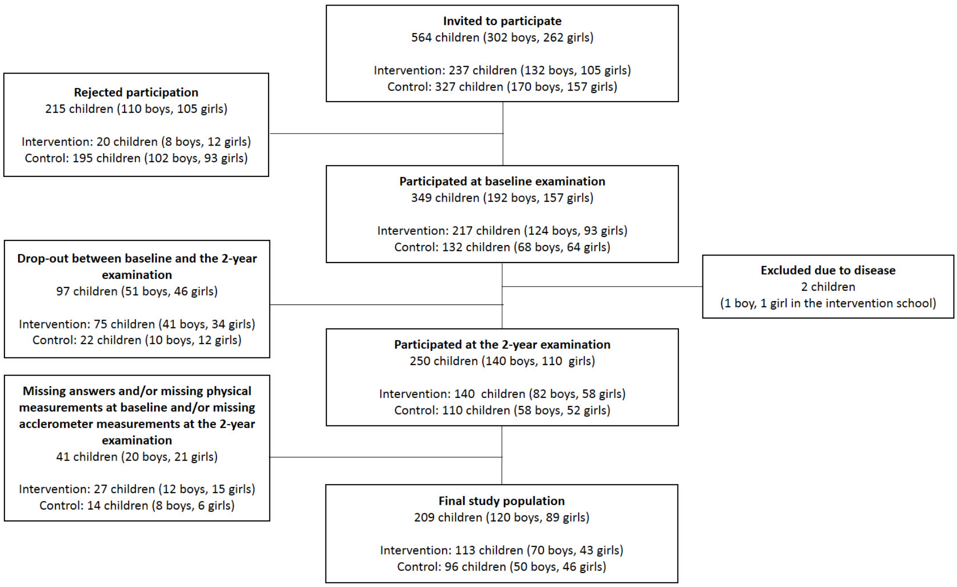

Figure 15. Flow-chart of the study-population in paper III.

Paper IV

In this study, we included children with complete data on all dependent (objectively measured PA) and independent factors included in the model. A total of 229 children participated in the accelerometer measurements and 199 children also had complete answers in the questionnaire's physical measurements. No missing data imputation was made. We excluded four outlier values in the analysis of GPA and two outlier values in the analysis of MVPA, thus including 195 children in the analysis for GPA and 197 for MVPA.

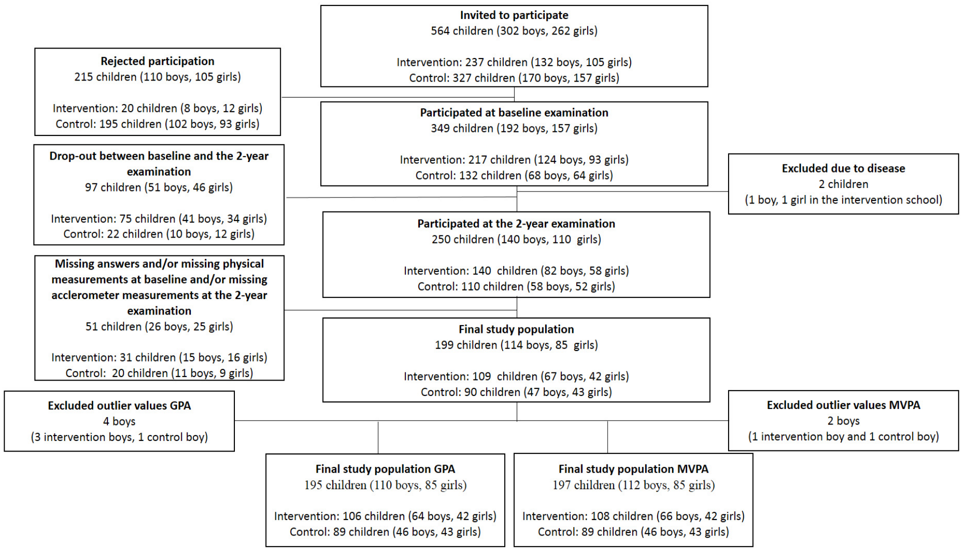

Figure 16. Flow-chart of the study population in paper IV.

Measurements

Physical Activity and Sedentary Activity

In papers I and II, PA was assessed by a questionnaire that assessed duration of organized leisure-time PA in summer and winter, respectively (Appendix 1), questions that in other studies have been shown to be associated with higher objectively measured GPA[81]. We estimated the annual duration of organized leisure-time PA as the mean value of PA during summertime and wintertime. Sedentary time was estimated as duration of daily screen time.

At the last follow-up, three years beyond the termination of the program, the questionnaire was modified and sedentary activity also included activities such as solving crosswords and reading books and PA was assessed as (1) weekly duration of PA (except walking) and (2) weekly duration of walking, separately in summer and winter (Appendix 2). If PA was only reported in one season, we used the given value as the mean annual duration of PA. Missing values in both seasons were excluded from the analysis. At the last follow-up, total duration of PA was estimated as the sum of i) walking as exercise (kilometres/week or hours/week) and ii) duration of exercise besides walking (hours/week). If answers were reported in kilometres/week, we converted it to duration/week by using the walking speed of six km/hour.

In paper III, PA was assessed by the MTI (Manufacturing Technology Incorporated, Fort Walton Beach, FL, USA) accelerometer model 7164. An accelerometer is a small device that is worn in a belt around the waist (Figure 17).

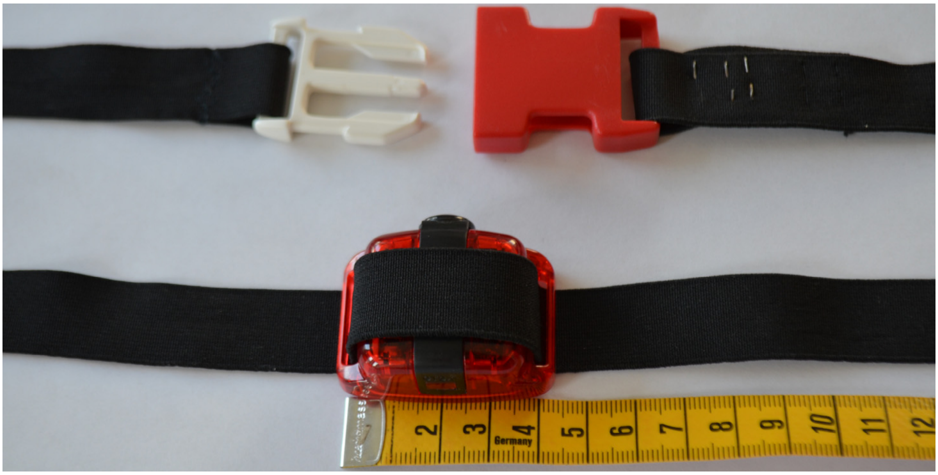

Figure 17. Picutre of the MTI acceleromter model 7164 that was used in the POP-study.

The accelerometer measures the frequency and intensity of movement in a vertical plane. Accelerometers use a sampling of accelerometer counts over a selected time period called an epoch, which normally varies between 5 and 60 sec[157]. Based on the typical movement pattern of short bursts of intense PA in children[74,75], we used a time epoch of 10 sec. Children were instructed to use the accelerometer during four consecutive days, including a minimum one weekend day. They were instructed to wear the accelerometer during the entire day and only removed it in water as the equipment was not water-resistant. The accelerometers started to record during the morning after the device was handed out, and continued to measure during four following days. The data was analyzed by a SAS-based software. Zero counts per minute during a constant sequence of 60 consecutive epochs (i.e., 10 min) was interpreted as the accelerometer was not worn and was removed from the analysis. After removal of missing data, the children needed a minimum of three separate days and a minimum eight hours of valid recording per day to be included in the analysis. A detailed description of the accelerometer measurements has been presented in previous studies[13,158].

In this thesis, we use GPA and min spent on moderate (e.g., brisk walking) and vigorous (e.g., running) PA as dependent variables. GPA was defined as the total accelerometer counts/valid minute of recording (mean counts/min) and MVPA as min above 3500 cpm (equivalent to >3 METs). This cut-off point was chosen based on previous studies presenting specific thresholds[13,14]. Before the accelerometers were used, they were calibrated against a standard vertical movement.

Anthropometry and Tanner Stage

Body height was measured with a Harpenden Stadiometer (Holtain Ltd, Pembrokeshire, UK) and body weight with a HL 120 electric scale (Avery Berkel, West Midlands, UK). We calculated BMI by the formula weight/height^2 (kg/m^2). We used Tanner stages to evaluate pubertal onset and physical maturation[119]. The Tanner classification includes five categories based on pubic hair development and size of the breasts (girls) and testicular volume (boys). The research nurses categorized the children into Tanner stages during the first years of the POP study. Later on this was done by the children themselves by the use of illustrations of the five different category Tanner stages.

Body Composition, Lean Mass and Fat Mass

We measured total body lean mass (kg) and fat mass (kg) by dual-energy X-ray absorptiometry (DXA; DPX-L, version 1.2z Lunar Madison, WI). Two research technicians conducted and analyzed the measurements. Lean mass included all fat-free mass, replicating predominantly muscle mass, but also ligaments, tendons and cartilage.

Figure 18. Picture of the dual-energy X-ray absorptiometry used in the POP-study.

Muscle Strength

We measured leg-strength (quadriceps and hamstrings muscles) during concentric isokinetic contractions by a computerized dynamometer (Biodex system III Pro®, with Biodex advantage software). The children were secured in the testing-chair with three belts and instructed to place their arms across their chest during testing. The knee was positioned at 90° of flexion and went through a 75° range of motion, stopping at 15° flexion. Using the speed of 60°/sec and 180°/sec, we tested concentric isokinetic knee extension and flexion peak torque. First, the child performed five maximal repetitions at 60°/sec, including both extension and flexion. After 30 sec of rest, 10 maximal repetitions at 180°/sec were performed. The highest peak torque for each of the extension and flexion variables were recorded in the unit of nanometre (Nm). All participants received verbal encouragement during the test. In this thesis, we use the extension variable of 180°/sec as a measure of muscle strength as this speed may be most similar to natural movement in children (e.g., playing, running) compared to the speed of 60°/sec that may be more similar to organized strength training[159].

Socio-ecological Factors

We assessed socio-ecological factors through a questionnaire (Appendix 3). The children answered an extended questionnaire at baseline, then modified questionnaires at each annual evaluation (predominantly assessing duration of PA). One part of the questionnaire was answered by the parents. Age, sex and relative age (i.e., born January 1 – June 30 or July 1 – December 31) was calculated from the children's personal birth date record.

Statistical Methods

We used IBM SPSS (Version 23, Chicago, IL, USA) for statistical analysis in papers I–III and IBM SPSS (Version 25, Chicago, IL, USA) in paper IV. $P<0.05$ was considered a statistically significant difference. Categorical data are presented as numbers (n) and proportions. Non-skewed data are presented as mean±standard deviations (SD) and skewed data as medians with interquartile ranges (q1,q3).

Paper I

We used Shapiro-Wilk to check for normality of the data. We presented group differences in duration of PA and sedentary activity as mean differences with 95% CI derived by bootstrapping of 10,000 samples. Analysis of covariance (ANCOVA) was adjusted for age and gender.

Papers II–III

We used Shapiro-Wilk test and plotted the data in histograms to check for normality of the data. We present group differences as regression coefficients or estimated difference from reference category with 95% CI adjusted for all other factors in the model.

Paper IV

We plotted the residuals for GPA and MVPA as boxplots to check for normality. We defined outlier values lower than the first quartile – 1.5*interquartile range or values higher than the third quartile +1.5*interquartile range and removed these from the analysis (four values for GPA and two values for MVPA). We used analysis of covariance (ANCOVA) to determine any associations between the included factors and GPA and MVPA unadjusted and adjusted for all other factors in the model and months between the baseline visit and follow-up visit two years later (conducted between August-December).

Summary of Papers

Paper I

Introduction. Many school-based PA interventions have succeeded in improving PA levels during the program, but few have examined whether such programs are associated with long-term effects beyond the termination of the intervention. Paper I examines whether a 40 min daily school PA intervention during the nine compulsory school is associated with changes in duration of PA and/or sedentary activity three years after termination of the program.

Methods. This prospective controlled intervention study included 81 children in an intervention group and 43 children in a control group. The intervention group had daily 40 min school PA whereas the control group had 60 min school PA per week during all compulsory school years. The intervention included a variety of activities within ordinary curriculum such as ballgames and athletics. All children were also followed three years beyond the termination of the intervention program. PA and sedentary activity were evaluated by questionnaires. Group comparisons are adjusted for age and gender, and data are provided as means with 95% CIs.

Results. At baseline there were no statistically significant group differences in duration of PA and sedentary activity. At the last evaluation during the intervention, the intervention group was more physically active than the controls (+4.5 (2.9 to 6.0) hours/week), without significant differences in sedentary activity (+0.6 (–2.5 to 3.9) hours/week). Three years beyond the termination of the program, the intervention group was still more physically active than controls (+2.7 (0.8 to 4.7) hours/week), without differences in sedentary activity (–3.9 (–9.7 to 1.7) hours/week).

Conclusion. Three years after the termination of the program, a 40 min daily school PA intervention throughout compulsory school is associated with higher duration of PA but without statistically significant differences in sedentary activity.

Paper II

Introduction. Better understanding of factors that associate with PA in children may aid the design of more effective interventions. This study aims to identify factors that independently associated with duration of PA in mean eight-year-old children.

Method. This cross-sectional, population-based cohort study included 300 children (175 boys and 125 girls) aged 7.7±0.6 years (mean±SD). We evaluated duration of PA/week, and factors within biological (e.g., gender), social (e.g., parental influences), and environmental (e.g., living conditions) domains with a questionnaire. We also measured anthropometrics (e.g., body weight) and physical performance (e.g. muscle strength). We used ANCOVA adjusted for all other factors included in the model, to identify factors that were independently associated with duration of PA.

Results. Children spent a median of 2.0 (0.5, 4.0) (q1, q3) hours/week on PA. Included factors explained 17% of the variance in PA. Factors that were independently associated with duration of PA in hours/week were male gender (+0.8 [95% CI: 0.1, 1.5] compared to female gender), older age (+0.7 [0.1, 1.4] for each year), parental duration of PA (+0.2 [0.0, 0.3] for each hour/week of parental PA), having minimum one parent regarding PA as important (+0.9 [0.2, 1.6] compared to having no parent regarding PA as important), and having a sibling being a member of a sports association (+1.0 [0.3, 1.7] compared to not have a sibling at all and/or not having a sibling active in a sports association).

Conclusions. This study has identified several factors that independently associate with duration of PA. Future intervention studies, with aim to increase PA in mean eight-year-old children, should test if the modifiable factors (e.g., family influences) could be addressed to increase the efficacy of any intervention program. Studies should also evaluate if non-modifiable factors (e.g., gender) could be used to highlight subgroups that may need extra support to be physically active.

Paper III

Introduction. Identifying socio-ecological factors, independently associated with PA in children may aid the design of more effective PA interventions.

Method. The POP-study is a prospective controlled intervention study with daily school-PA. This study includes 120 boys and 89 girls aged 9.8±0.6 (mean±SD) years from the POP-study. We measured PA with accelerometers during three to four consecutive days mean two years after the baseline exam. We defined GPA as mean daily cpm and MVPA as daily min > 3500cpm. Biological, social and environmental factors were collected by questionnaires, anthropometric measurements and physical performance tests. An ANCOVA analysis, adjusted for all other factors in the model, was used to identify factors that were independently associated with PA. Data are provided as mean±SD or mean (95% CI).

Results. In all children, daily GPA was 687±212 cpm and daily MVPA 40±18 min. Female compared to male sex was associated with -66 (-123,-9) daily GPA, a 10-unit lower body height with -69 (-113,-25), 1 year younger age with -55 (-108, -1) and having 60 min school-PA/week (control schools) with -82 (-148,-16) compared to 40 min daily school-PA (intervention school) GPA. Female gender was associated with -7 (-11,-2) min MVPA and 10-unit lower body height with -4 (-8,-1) min MVPA.

Conclusions. Female sex, lower body height, younger age and having school PA 60 min/week compared to 40 min/day were factors that were independently associated with lower objectively measured PA. The identified modifiable factors could be targeted for a possible improved effect of a PA intervention program, whereas studies should evaluate whether the non-modifiable factors could be used to identify subgroups in need of support to be physically active.

Paper IV

Introduction: In a population-based cohort of mean eight-year-old children, this study aims to evaluate whether any socio-ecological factor(s) were associated with levels of PA two years later.

Method: We included 195 children from the POP study cohort aged 7.7±0.6 (mean±SD) years. Socio-ecological factors were collected at baseline by questionnaires and anthropometrics by measurements. PA was measured with accelerometer during three to four consecutive days a mean two years later. GPA was defined as mean daily cpm, MVPA as min/day >3500cpm. We used ANCOVA, adjusted for all other factors in the model, to evaluate whether included factors were independently associated with PA. Data are provided as mean±SD or mean (95% CI).

Results: Daily GPA was 689±201 cpm and the children spent 41±17 min on MVPA. Female sex was associated with -131 [-183,-79] cpm GPA compared to male sex, each 10 centimeters shorter body height with -49 [-95,-27], each unit higher body mass index (BMI) with -26 [-37, -15] and allocation to 60 min school-PA/week with -74 [-132,-16] compared to allocation to 40 min school-PA/day. Female sex was associated with -10 [-15, -6] min MVPA compared to male sex and each unit lower BMI with -2 [-3, -1] min MVPA.

Conclusions: Female sex, higher BMI and lower body height are factors that associate with lower future childhood PA levels. We speculate that these attributes could be identified in the first general school-health examinations, as a possible approach to highlight groups of children that may need support to keep an adequate level of PA. It also seems as if the school is one arena where an intervention program can promote PA in childhood.

General Discussion

In modern society, inactivity has reached pandemic proportions in both children and adults and annually accounts for millions of preventable deaths globally[3,4]. Many countries also spend enormous resources on pharmacological and surgical methods to treat inactivity-related diseases[2] such as obesity[160], type II diabetes[161] and cardiovascular diseases[162]. It would probably be better if we could intervene before inactivity and related diseases occurs. The core of the POP-study is to use daily school-PA in schoolchildren during all compulsory school years to establish healthy PA behaviors in childhood and hopefully induce a healthy lifestyle that is retained in adulthood.

Schools to Promote Physical Activity in Children

Many studies have evaluated the effects of school-based PA programs on several different outcomes[146,150,151], but these studies have in general been short-term without evaluating possible long-term effects beyond the termination of the program. Previous reports from the POP-study have opposed the Activity Stat Theory, showing that it seems possible to increase the total duration of PA without affecting sedentary activity[100,101]. As voluntary PA habits are known to track from childhood to adulthood[8,9], it would be interesting to evaluate whether the increased duration of PA found in previous POP-studies[100,101] persists also after termination of the intervention.

In **Paper I**, we found that a daily 40 min school-PA intervention during the nine compulsory school is associated with a more physically active lifestyle beyond the program, into late adolescence. Three years after termination of the intervention, a higher self-estimated duration of PA without differences in sedentary activity was found in children within the former intervention group compared to children in the former control group. Although **Paper I** is not a randomized study, it ought to be emphasized that after graduation from compulsory school and termination of the intervention (at a mean age of 15 years), all children were spread out to different schools within the city of Malmö. Our conclusion from this study is that it seems possible to induce a more physically active lifestyle that remains beyond the termination of the intervention by implementing daily school-PA throughout compulsory school.

In **paper III**, we confirmed that additional school-PA, independently of all other factors included in the study, is associated with higher objectively GPA compared to PA according to the Swedish standard of 60 min/week. This finding supports the view that the intervention actually leads to higher total level of PA and that the results are not due to potential confounding factors such as having more well-educated or more physically active parents. Even more, as shown in **Paper IV**, being allocated to high duration of school PA (and thereby exposed to 40 min of daily school-PA instead of 60 min of weekly school-PA) is also independently associated with higher objectively measured PA levels two years later. Taking these findings together, there are substantial data that support that schools have a great potential to establish healthy PA behavior in children, regardless of a variety of other socio-ecological factors.

Socio-Ecological Factors Associated with Childhood Physical Activity

According to the SEM, there are many factors across several domains that influence PA in children[111]. In addition, many of these factors co-exists and interact with each other, making the PA behavior in children complex to understand[111,163,164]. As so many factors influence the level of PA in childhood, it is hypothetically possible to advocate many different types of interventions with a favourable outcome (increased level of PA). However, many studies only evaluate the influence of one factor at a time on childhood PA, without considering the broad, comprehensive perspective when combining several of these factors. For example, some suggest that we should spend resources on building new schoolyards (environmental)[165], whereas others are trying implementation of family programs (social)[166] or to increase school-PA (environmental)[100,101], to encourage an active lifestyle in children. Few raise the question of the independent influence of each socio-ecological factor on PA levels in children. In other words, if we initiate an intervention with the aim of increasing PA in children, which factor(s) would hypothetically be most effective to address?

Papers II-III found that female sex was associated with lower level of PA compared to male sex, indicating that girls are a subgroup of children in need of extra support to be physically active. This finding supports previous reports in the literature[66,115,167], even though the citied studies infer that the sex discrepancy to the disadvantage of girls develops in the adolescent years. In contrast, **Paper II** infers that sex discrepancies in childhood PA exist already in mean eight-year-old children. To prevent adolescent girls from developing even lower PA levels, preventive interventions should probably be initiated in girls at younger ages than in adolescence. We should also emphasize that this sex difference existed independently of several other socio-ecological factors in the model (including common biological differences between boys and girls such as muscle strength, fat mass and lean mass), indicating that sex difference in PA are possibly related to other factors than differences in anthropometry. More research is needed on why these sex differences occur and how we should promote PA in young girls.

We also found associations between age and PA (**paper II-III**). This association was positive in the age range six to nine years (**paper II**) and negative in age range eight to 11 years (**paper III**). These findings support previous research, indicating that PA levels increases in small children to a certain age, but declines with increased age in the adolescence years and more so in girls than boys [66,115].

In **paper III**, we also found that shorter body height was associated with lower PA. One explanation could be that taller children in these ages may have advantages in sport performance compared to shorter children and since they then perform better, they choose to be more physically active than shorter children who have a disadvantage in performance. None of our papers could identify a true RAE (i.e., an association between being born early or late on the year and PA levels), but it is probably not the birth-date itself that is of importance in the RAE, but rather the more advanced maturation in the relatively older children. Previous research has described an association between being born early in the year and taller body height/early maturation[168]. Therefore, we cannot in total rule out that taller (and then also more mature) children in these ages have a maturational advantage over shorter children. Our finding must also only be regarded as hypothesis-generating, but it highlights an interesting question; would grouping according to body height in addition to chronological age during PA and competitive sport provide more equal opportunities for enjoyment and success for all children?

Papers II and III provide new knowledge on factors that are independently associated with childhood PA. The modifiable factors identified in these papers ought to be tested in prospective controlled intervention studies. Our studies could only state that there are associations, but future studies should now test whether interventions with changes in these factors actually increase the level of PA. On a population-based level, prospective studies ought also to test whether the identified non-modifiable factors could be used to identify children at risk of developing lower levels of PA later in life, and if so, whether interventions targeting these subgroups can reduce the gap between the most and least physically active children.

Socio-Ecological Factors Associated with Future Physical Activity Levels

During the recent few decades, the gap has grown between the most and least physically active children[102,103]. To improve general health in society, it is probably more important to focus the attempts on improving PA levels in the least physically active children. It would then be advantageous to be able to identify children at risk of developing lower PA levels before inactivity occurs, so that interventions could be instituted in time. The factors we have identified in **papers II–III** were therefore tested in a prospective design. In **Paper IV**, we found that female sex, lower body height and higher BMI, independently of the other included factors, were associated with lower levels of PA two years later. As all Swedish children undergo compulsory school health examinations, we speculate that these examinations could be used to identify children on a group-level that may develop lower level of PA later in life. This knowledge is of importance as it may provide the possibility for future interventions to target these groups of children in time, before lower level of PA has developed and hopefully in a longer perspective also reduce the occurrence of inactivity-related diseases.

We must emphasize that our findings in this thesis should be interpreted on a population-based level and probably cannot point out specific individuals who ultimately will be physically active or not. For example, it may be girls in the control group who, in spite of having two independent factors associated with lower level of PA, are sufficiently physically active also on a competitive level. In addition, within some sports such as gymnastics and weight lifting, there is actually an advantage in being short, and many of these athletes are very muscular, then also having a higher BMI.

Strengths of the Studies

The strengths of the studies in this thesis include the population-based prospective controlled study design and the long follow-up period in paper I. The follow-up several years after termination of the program, improves our ability to discuss the long-term effects of a PA intervention.

Another advantage is that the intervention included a variety of regular activities in the school curriculum, provided at a level so that most children could participate and not get bored. The intervention did not require any additional costs, extra education or extra teachers. This infers that it in general is practically possible to apply our program in most schools, even on a national level.

The drop-out analysis, reporting no anthropometric differences in those who accepted and those who declined participation at baseline[13] indicates that our inferences could be generalized. Including schools from the same geographical area, and the fact that all these schools had similar duration of PA before study start, reduces the risk of selection bias between the intervention and control groups.

As the children were allocated to each school depending on their residential address, and as all school PA was mandatory, our study cohort could be regarded as population-based. As there is no gold standard for how to estimate the level of PA in children, it is also a strength that we used both accelerometers and questionnaires to assess level of PA.

It also seems probable that the use of the socio-ecological approach could contribute to more knowledge when evaluating the complexity of factors that influence PA in children, instead of focusing on only one single factor at a time (e.g., building new playgrounds or implementing daily school PA) without considering the relation to other factors that influence physical behavior in children.

Limitations of the Studies

The POP study is not a randomized controlled trial (RCT). Randomization was discussed before study start, but not possible to conduct due to resistance from parents, teachers and pupils. Furthermore, it would have been virtually impossible to keep a randomization of children within the same classes during all nine compulsory school years. In addition, the studies included in this thesis could not be blinded. That is, our studies did not reach the highest level of evidence. The consequence is that we cannot draw any causal inferences.

We are also well aware of the limitations when estimating PA in children. Our questionnaires, which use a self-reported method of PA, entail recall bias and provide no information about PA intensity or PA beyond the duration of organized PA. Another disadvantage is that our questionnaire is not validated. Accelerometers are undisputedly an objective method that can measure both duration and different intensities of PA[82]. Limitations with our equipment was that the device was not water resistant, thus missing these types of PA, and that the equipment missed PA with no vertical acceleration, such as cycling. It would also be advantageous to measure PA with accelerometers annually and during summer and winter respectively with a longer duration than three to four days.

The different participation rate in the intervention and control schools is another limitation that induces the risk of bias. Of the 564 children who were invited to participate at baseline, 217 out of 237 children (92%) from the intervention school and 132 out of 327 children (40%) from the control schools agreed to participate in the study. It is possible that only the most motivated and physically active children participated in the control schools. The cost of the long-term follow-up in paper I is the high drop-out frequency that increases the risk of selection bias in all four schools, with only the most physically active children participating at the follow-up three years beyond the termination of the program.

However, the baseline drop-out analysis could not identify any antopometric differences between those who participated in the POP-study and those who did not, indicating that our inferences could be generalized. It could also be discussed, whether the large publicity of the POP-study in our region and the annual study measurements also influenced the control children, so that they gradually become more involved in PA than children without such attention.

It would also be of interest to evaluate the socio-ecological development in the neighborhood during the study period, as these settings may have changed during such a long study period. Differences in these aspects could have influenced our inferences, as children of families with higher socio-economic status often engage more in organized leisure-time PA than children in families with lower socio-economy[139]. An even larger study-cohort would enable sex-specific analysis and would increase knowledge in associations of PA in boys and girls separately.

Another limitation is that we did not have access to all potential explanatory factors of interest. For example, we could not include season variability, self-efficacy or facility access in the neighborhood, as we did not have access to these factors. When the study was initiated in 1999–2000, children had in general lower accessibility to screens (e.g., owning their own iPad, computer and/or smartphone) than they have nowadays. Today, we would include more questions regarding screen time activity and sedentary behavior than what we examined 20 years ago, and we would have used a validated questionnaire when conducting registration of lifestyle factors and duration and intensity of PA, both organized and unorganized activities. It is also important to mention that many other factors probably have affected the children before eight years of age.

Conclusions

The general conclusions from this thesis are that;

- A daily 40 min school-PA intervention (compared to 60 min per week) throughout the compulsory school-years, is associated with higher duration of PA both during and three years after termination of the program, without significant differences in duration of sedentary activities. These results refute the Activity-Stat theory and indicate that it is possible to teach children the habit of an active lifestyle.
- Regardless of several other socio-ecological factors, a daily 40 min school-PA intervention (compared to 60 min per week) associate with higher level of PA at mean age 10-years. This finding supports the view that the daily school-PA actually leads to higher total level of PA and that the results are not due to other potential confounding factors included in the model.
- Before intervention start at mean age eight years, biological attributes and factors at family level are independently associated with duration of PA. After two years with the intervention, at mean age 10 years, biological factors and having more school PA were independently associated with total objectively measured amount of PA. We therefore speculate that family-based interventions and/or schools' PA interventions are feasible strategies to increase levels of PA in these ages.
- As female sex, shorter body height and higher BMI and being allocated to lower level of school-PA in mean eight-years old children are associated with lower level of PA two years later, we speculate that school-PA intervention is a feasible strategy to promotes childhood PA. In addition, the first grade general school-health examination could be an opportunity to, on a group level, identify children with increased risk of developing lower level of PA, possibly suitable for timely targeted PA interventions to prevent lower level of PA.

Future perspectives

Paper I examines the long-term effects of daily PA in school during the compulsory school years, also beyond termination of the program. As we found that children attending the intervention school were more physically active than children attending the control schools three years beyond the program, further studies should evaluate whether these beneficial effects remain in an even longer perspective and whether the individuals with higher PA actually develop fewer inactivity-related diseases later in life. As sedentary activity is an independent contributor to adverse health effects, future studies should also focus more on sedentary behavior and how to limit the time children spend in front of different screens.

Papers II and III examine the independent association between several socio-ecological factors of self-estimated duration of PA (**paper II**) and objectively measured PA (**paper III**). Futures studies ought to examine if interventions that target modifiable factors (parental attitude towards PA) for change and/or give extra support for children with non-modifiable factors associated with lower level of PA (e.g., female sex) actually can increase level of PA.

In **paper IV**, we found that female sex, shorter body height and higher BMI, independently of all other factors included in the model, were associated with lower PA levels two years later. Future studies ought to evaluate whether the already established school health examinations could use these factors to, on a population-based level, identify children at greater risk of developing lower level of PA. If so, further studies should also examine whether we can prevent lower level of PA, especially among the least physically active ones, to reduce the polarization of PA levels in children. Further studies should also be done as to see if the same factors are independently associated with PA in other ages and socio-economic settings than in our studies and include other factors of possible interest that were not evaluated in this thesis.

Summary in Swedish; Populärvetenskaplig Sammanfattning

Fysisk aktivitet bidrar flera positiva hälsoeffekter bland barn och ungdomar såsom bra kondition[158] god muskel[169] och skelettstyrka[169] samt en hälsosam kroppsvikt[30]. Fysisk aktivitet är också förknippat med god psykisk hälsa[38-41] och bra skolresultat[44,46], medan fysisk inaktivitet är förknippad med förkortad livslängd och sämre livskvalitet[15,62-64,71,170]. Trots att vi idag har god kunskap om de hälsovinster som följer en fysisk aktiv livsstil, spenderar endast var femte pojke och var tionde flicka i Sverige minst en timme om dagen på fysisk aktivitet vid 11-års ålder[37]. Även om många sjukdomar relaterade till inaktivitet debuterar i vuxen ålder finns anledning att oroa sig över dessa siffror då motionsvanor i barndomen tenderar att följa med in i vuxenlivet[8,9]. Samhället bör därför arbeta aktivt för att främja fysisk aktivitet bland barn och ungdomar. Skolan är sannolikt en bra arena för interventioner som syftar till att främja fysisk aktivitet då den når alla barn i samhället, även dem som inte redan har ett etablerat intresse för idrott eller har föräldrar som betalar för dyra idrottsaktiviteter på fritiden.

Bunkefloprojektet (engelska; Pediatric Osteoporosis Prevention (POP) study) är en prospektiv kontrollerad interventionsstudie som startades år 1999-2000 på fyra närliggande grundskolor i Malmö. Vid studiestart erbjöds alla barn i årskurs ett och två (ålder sex till nio år) på de fyra skolorna att delta. Interventionsskolan (Ängslättsskolan) införde 40 minuters daglig fysisk aktivitet medan kontrollskolorna (Ribbersborsskolan, Fridhemsskolan och Mellanheds-/Slottstadens skola) fortsatte med 60 minuters fysisk aktivitet per vecka som då var standard enligt svensk läroplan. Interventionen pågick genom hela grundskoleperioden och innehöll blandade aktiviteter såsom bollsport, friidrott och dans.

Under hela interventionen genomgick barnen årligen mätningar av bland annat längd och vikt och fyllde i ett frågeformulär som utvärderade livsstil, stillasittande tid och fysisk aktivitet. Två år efter studiestart genomförde barnen tre till fyra dagars accelerometermätningar. Förutom årliga uppföljningar under pågående intervention, genomfördes också ett uppföljningsbesök tre år efter att barnen slutat grundskolan och gick sista året på gymnasiet.

Tidigare studier inom Bunkefloprojektet har visat att det går att öka barns fysiska aktivitetsnivåer under pågående intervention[100,101]. Vi vet också att motionsvanor i barndomen tenderar att följa med in i vuxen ålder[8,9,171]. Detta fenomen kallas för tracking och är huvudsakligen studerat på frivilliga aktivitetsnivåer. Desto mindre studerat är vad som händer med barns motionsvanor efter att hälsofrämjande interventioner, liksom Bunkefloprojektet, avslutas. Går det även att "tracka" högre fysiska aktivitetsnivåer som uppnåtts via en skolintervention, även efter att interventionen avslutas? Med andra ord, kan vi lära barn en aktiv livsstil som följer med i vuxen ålder?

Sista året på gymnasiet (tre år efter interventionens slut) fann vi att individer som gått på interventionsskolan var i genomsnitt tre timmar mer fysiskt aktiva per vecka än de som gått på kontrollskolorna. Dessutom spenderade de som gått på interventionsskolan i genomsnitt fyra timmar mindre tid per vecka på stillasittande aktiviteter, i jämförelse med de som gått på kontrollskolan. Även om det bara var skillnaderna i fysisk aktivitet som uppnådde statistisk signifikans är det intressant att även stillasittandet var fyra timmar mindre i interventionsgruppen, eftersom studier visat att stillasittande är en oberoende riskfaktor för ohälsa, oavsett hur mycket man rör på sig[15,62-64,71].

Förutom skolmiljön, finns det en uppsjö med andra faktorer som också påverkar barns motionsvanor[172]. Den socio-ekologiska läran menar att det inte går att se endast en faktor (som exempelvis en intervention med daglig skolidrott) som förklaring till ett beteende, utan att man istället bör beakta ett samspel av olika faktorer på flera olika nivåer (individuella/biologiska, sociala och miljö) som motivering till ett visst beteende[109-111]. Med den socio-ekologiska läran i beaktande, ställde vi oss frågan hur stort inflytande vår intervention har på barns motionsvanor, i jämförelse med en rad andra faktorer (såsom inflytande från familj, fysiska attribut och boendeform) som också påverkar aktivitetsnivåer hos barn. Är det skolbaserade interventionsprogram vi ska satsa på, eller finns det andra faktorer som spelar större roll?

Vid studiestart, när barnen var i genomsnitt åtta år gamla (åldersspann sex till nio år) och innan vi ökade skolgymnastiken på Ängsslättsskolan, fann vi att vara flicka (jämfört med att vara pojke), att vara yngre (jämfört med att vara äldre), att ha föräldrar med låg fysisk aktivitet (jämfört med att ha föräldrar med hög fysisk aktivitet), att inte ha syskon alls eller ha syskon som ej är fysiskt aktiva (jämfört med att ha minst ett fysiskt aktivt syskon), och att ha föräldrar som inte tycker det är viktigt att motionera (jämfört med att ha minst en förälder som tycker det är viktigt att motionera), var associerat med en lägre nivå av fysisk aktivitet.

När barnen blivit i genomsnitt 10 år gamla (åldersspann 8-11 år) och då barnen i Ängsslättskolan hade mer skolgymnastik än övriga barn, fann vi att vara flicka (jämfört med att vara pojke), att ha kortare kroppslängd (jämfört med att ha längre kroppslängd), äldre ålder (jämfört med att ha lägre ålder) och att ha fysisk aktivitet 60 min/vecka (kontrollgrupp) jämförelse med att ha 40 minuters fysisk aktivitet i skolan per dag, var associerat med en lägre nivå av fysisk aktivitet mätt med accelerometrar.

Ur ett folkhälsoperspektiv skulle det sannolikt vara mer positivt att öka den fysiska aktiviteten bland dem som rör sig minst än att göra de redan aktiva ännu mer aktiva. Vi funderade därför på om det finns faktorer som associerar med lägre fysiska aktivitetsnivåer längre fram i livet, i förhoppning om att framtida interventioner ska kunna förebygga inaktivitet bland de barn som har störst behov av stöttning till rörelse redan innan en inaktiv livsstil uppstår.

Vid studiestart (genomsnittsålder åtta år) fann vi att vara flicka (jämfört med att vara pojke), att vara kortare (jämfört med att vara längre) och att ha ett högre BMI (jämfört med att ha ett lägre BMI) samt att ha 60 minuters fysisk aktivitet per vecka (jämfört med att ha 40 minuters fysisk aktivitet per skoldag), var faktorer associerade med en lägre nivå fysisk aktivitet mätt med accelerometrar två år senare (genomsnittsålder 10 år).

Slutsatserna av denna avhandling är att en intervention med daglig skolidrott är associerad med mer fysisk aktivitet även efter grundskolan, utan att påverka graden av stillasittande aktivitet. Precis som vi lär våra barn att borsta sina tänder och de fortsätter med detta i vuxenlivet, verkar det som att vi även kan lära barn en aktiv livsstil genom att tidigt i livet implementera regelbunden daglig fysisk aktivitet. Dessutom fann vi att vid 10-års ålder är skolinterventionen associerad med högre nivå fysisk aktivitet mätt på ett objektivt sätt, oberoende flertalet andra socio-ekologiska faktorer. Detta stärker resonemanget om att det faktiskt är den utökade fysiska aktivitet i skolan som påverkar barns fysiska aktivitetsnivå, och att effekten av Bunkefloprojektet inte beror på andra socio-ekologiska faktorer.

På gruppnivå spekulerar vi kring om man via skolhälsovården kunde främja fysisk aktivitet bland de subgrupper som riskerar att bli inaktiva längre fram i livet. De faktorer vi identifierat (flickor, kortare barn (och därmed sannolikt de som kommer senare i pubertet) och dem med högre BMI) kan vi identifiera via redan etablerade skolhälsoundersökningar. Att ge extra stöttning till fysisk aktivitet i dessa grupper skulle eventuellt kunna minska gapet mellan de barn som är mest och minst fysisk aktiva, och på lång sikt minska insjuknandet i inaktivitetsrelaterade sjukdomar.

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Appendix 1

Extract from the questionnaire used in the POP-study during the compulsory school years including question 93-96 and question 108 that were used to estimate duration of leisure-time physical activity and sedentary time. The questions are provided in Swedish:

Idrott och motion

93 Tränar Du i en idrottsklubb/ar under vinterhalvåret?

Nej Ja

94 Om Ja, Idrott 1 .... tim/vecka...........

Idrott 2...................................... tim/vecka...........

Idrott 3..................................... tim/vecka...........

95 Tränar Du i en idrottsklubb/ar under sommarhalvåret?

Nej Ja

96 Om Ja, Idrott 1 .... tim/vecka...........

Idrott 2...................................... tim/vecka...........

Idrott 3..................................... tim/vecka...........

108 Hur många tim/dygn tillbringar Du framför TV, TV-spel eller dator? .... tim

Appendix 2

Extract from the questionnaire used in the POP-study mean 4-years after termination of the program including question E1, E4, E9a, E9b to estimate duration of physical activity and sedentary time. The questions are provided in Swedish:

Fråga E1 **Hur mycket promenerar du per vecka?** *(ange 0 under respektive rubrik om du inte promenerar alls).*

	Sommartid		***Vintertid***		Upplever du promenaden som konditionskrävande	
	Km/vecka	*tim/vecka*	*Km/vecka*	*tim/vecka*		
I arbetet och/eller skolan	⎿⏊⏌ km	⎿⏊⏌ timmar	⎿⏊⏌ km	⎿⏊⏌ timmar	0 ☐ Nej	1 ☐ Ja
Till och från arbetet/skolan	⎿⏊⏌ km	⎿⏊⏌ timmar	⎿⏊⏌ km	⎿⏊⏌ timmar	0 ☐ Nej	1 ☐ Ja
Som motion/rekreation	⎿⏊⏌ km	⎿⏊⏌ timmar	⎿⏊⏌ km	⎿⏊⏌ timmar	0 ☐ Nej	1 ☐ Ja
Promenader för övrigt	⎿⏊⏌ km	⎿⏊⏌ timmar	⎿⏊⏌ km	⎿⏊⏌ timmar	0 ☐ Nej	1 ☐ Ja

Fråga E4 **Om du motionerar, förutom promenader hur många timmar/vecka tränar du sammanlagt?**

Sommartid ⎿⏊⏌ *tim/vecka*

Vintertid ⎿⏊⏌ *tim/vecka*

Fråga E9a **Ungefär hur många timmar tittar du på TV, spelar TV-spel, sitter framför datorn på fritiden?**
(ange 0 timmar om du inte gör någotdera)

⎿⏊⏊⏌ timmar/vecka

Fråga E9b **Förutom ovanstående, hur många timmar där utöver, tillbringar du sittande, t ex läser böcker, löser korsord, handarbetar eller sitter i bil mm på fritiden?**

⎿⏊⏊⏌ timmar/vecka

Appendix 3

Extract from the questionnaire used in the POP-study during the intervention including questions that were used to assess socio-ecological factors in Paper II-IV. The questions are provided in Swedish:

13 Vem bor Du med? LIV_WITH
- ❑ Båda föräldrar
- ❑ En förälder
- ❑ Annan person
- ❑ En förälder + styvförälder
- ❑ Annat LIV_OTH ……………………

14 Hur bor Du nu? LIV_FORM
- ❑ Villa
- ❑ Lägenhet
- ❑ Annan boendeform LIVF_OTH………

15 Har Du syskon? SIB_ANY
- ❑ Nej
- ❑ Ja

23 Vilken utbildning har Din mamma? EDUSCHM
- ❑ Folk/grundskola
- ❑ Realskola
- ❑ Yrkesutbildning
- ❑ Gymnasium
- ❑ Högskoleutbildning

24 Vilken utbildning har Din pappa? EDUSCHF
- ❑ Folk/grundskola
- ❑ Realskola
- ❑ Yrkesutbildning
- ❑ Gymnasium
- ❑ Högskoleutbildning

29 Hur många timmar per vecka är Din mamma fysiskt aktiv utanför arbetstid med t.ex. cykling eller idrott? ……….. timmar/vecka EXERMOHR

30 Hur många timmar per vecka är Din pappa fysiskt aktiv utanför arbetstid med t.ex. cykling eller idrott? ……….. timmar/vecka EXERFAHR

35 Har Du något syskon som är aktiv i en idrottsförening? ACT_SIB ❑ Nej ❑ Ja

92 Tycker Du att gymnastik och idrott är roligt? PT_EXER ❑ Nej ❑ Ja

The following questions were answered by the mother and father separately:

	Instämmer helt	Instämmer delvis	Instämmer inte alls
1 Varje kropp är vacker på sitt sätt BODY_BEA	❑	❑	❑
2 Man bör sträva efter att hålla sig i trim INSHAPE	❑	❑	❑
3 Man bör sträva efter att bevara sin ung- KEEP_YOU domlighet	❑	❑	❑
4 Det är viktigt att se välvårdad ut LOOKTIDY	❑	❑	❑
5 Kroppens utseende är betydelsefullt BO_LO_IM	❑	❑	❑
6 Jag bryr mig inte om mitt utseende NOIMP_LO	❑	❑	❑
7 Jag gillar att motionera LIKEEXER	❑	❑	❑
8 Jag försöker motionera så ofta som möjligt EXER_OFT	❑	❑	❑
9 Det är viktigt att ofta belasta sin kropp, så att man blir starkare IMP_STRO	❑	❑	❑
10 Jag känner mig fysiskt stark PHYSSTRO	❑	❑	❑
11 Jag känner mig psykiskt stark PSYCSTRO	❑	❑	❑
12 Jag avhåller mig från tobak AV_TOBA	❑	❑	❑
13 Det är viktigt att avhålla sig från tobak IMAVTOB	❑	❑	❑
14 Inom vår familj tycker vi att det är vik- FAIMPEXE tigt med motion	❑	❑	❑
15 Jag skulle motionera mera, om det hade funnits bättre möjligheter där jag bor EXERMORE	❑	❑	❑

Authour information

This thesis explores how a daily school-based physical activity intervention throughout the compulsory school-years affect duration of physical activity and sedentary activity beyond termination of the program. It also explores socio-ecological factors associated with physical activity during the first years of compulsory school and if any socio-ecological factor(s) also associate with future PA levels in eight-year old children.

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