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Physical Activity in 6-10 Year Old Children:

variations over time, associations with metabolic risk factors and role in obesity prevention

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“Knowing is not enough; we must apply.

Willing is not enough; we must do.”

Johann Wolfgang von Goethe (1749-1832)

To my family

ABSTRACT

Background and Aims: Childhood overweight and obesity are emerging health problems in all western countries and also in urban areas in developing countries. In Sweden, the prevalence of overweight and obesity has been rapidly increasing. The aim of this thesis was to assess the efficacy of a school-based intervention programme in reducing the prevalence of overweight in 6-10 year old children. Another aim was to examine the stability of physical activity (PA), and differences in PA patterns in relation to age and gender. Also, to study differences in metabolic risk between groups of normal weight and moderately overweight children and associations with PA and cardio-respiratory fitness (CRF).

Material and Methods: 3135 boys and girls aged 6 to 10 years were included in the study. Ten schools were selected in Stockholm county area and randomised to intervention (n=5) and control (n=5) schools. Low fat dairy products and whole grain bread were promoted and all sweets and sweetened drinks were eliminated in intervention schools. PA was aimed to increase by 30 minutes per day during school time and sedentary behaviour restricted during after school care time. Eating habits at home were assessed by parental report. Eating attitudes were evaluated by self-report. PA was objectively measured during 7 days by accelerometry in 1293 children. Two sub-groups of children provided repeated measurements of physical activity. 68 children were selected based on their BMI and categorised into normal weight and overweight/obese. CRF was measured with a maximal ergometer cycle test and body composition with dual-energy x-ray absorptiometry (DXA). Oral glucose tolerance test was performed and triglycerides (TG) and HDL-cholesterol were measured from fasting blood samples. A metabolic risk score was computed and calculated as the mean of the standardised values of the outcome scores (i.e. insulin, glucose, TG, HDL and blood pressure).

Results: The prevalence of overweight and obesity decreased by 3.2% (from 20.3 to 17.1) in intervention schools compared to an increase of 2.8% (from 16.1 to 18.9) in control schools ($P<0.05$). The results showed no difference between intervention and controls, after cluster adjustment, in the longitudinal analysis of BMI SDS changes. However, a larger proportion of the children who were initially overweight reached normal weight in the intervention group (14%) compared to the control group (7.5%) ($P=0.017$). PA did not differ between intervention and control schools after cluster adjustment. Eating habits at home were found to be healthier among families with children in intervention schools at the end of the intervention. There was no difference between children in intervention and control schools in self-reported eating attitudes. Mean daily PA differed significantly across age groups ($P<0.001$) and was significantly lower during weekends compared to weekdays in all age groups ($P<0.001$). This decline was similar across low, medium and highly active children. The difference in mean PA between boys and girls was highest during school time ($P<0.001$) and after school care time ($P<0.001$). Baseline physical activity was significantly correlated with physical activity at follow-up ($r=0.59$). There was a significant difference between normal weight and overweight children in clustered metabolic risk ($P=0.03$), insulin (AUC) ($P=0.01$), fasting insulin ($P=0.003$) and systolic blood pressure ($P=0.02$). PA and CRF did not differ significantly between groups. PA and CRF were negatively associated with insulin levels.

Conclusions: A school-based intervention can reduce the prevalence of overweight and obesity in 6-10 year old children and may affect eating habits at home. The effect of the intervention was possibly due to its effect on healthy eating habits at school and at home rather than on increased levels of PA. The decline in PA in children may start already at the age of 6 years. The difference in PA levels between girls and boys is most pronounced during school time. PA levels are disproportionally low during weekends. Repeated measurements show that PA levels are fairly stable over time. Metabolic risk factors are elevated in moderately overweight pre-pubertal children compared with normal weight controls. This is not due to lower PA or CRF in the overweight group although PA and CRF were associated with lower insulin levels. This suggests a detrimental effect of a moderate excess of adiposity already at an early age.

SAMMANFATTNING (SUMMARY IN SWEDISH)

Bakgrund och syfte: Fetma och övervikt är i dag ett av våra största folkhälsoproblem. Mellan 18-25% av svenska 10-åringar är antingen överviktiga eller feta. Det är en mycket kraftig ökning som har ägt rum de sista åren. Syftet med denna avhandling var att undersöka om man genom ett interventionsprogram i skolan kan förebygga och minska övervikt och fetma hos barn i åldern 6-10 år. Vidare att studera hur stabil fysisk aktivitet är mellan två mättillfällen och att studera skillnader i aktivitetsmönster mellan kön och mellan olika åldrar. Dessutom att undersöka skillnader i metabol risk mellan normalviktiga och överviktiga/feta barn och att studera samband med fysisk aktivitet och maximal syreupptagningsförmåga.

Material och metod: 3135 pojkar och flickor i åldern 6-10 år deltog i ett preventionsprojekt, STOPP (Stockholm Obesity Prevention Project). STOPP är en randomiserad studie med fem interventionsskolor och fem kontrollskolor som pågick mellan 2001 och 2005. De förebyggande insatserna i projektet var framför allt att förbättra kosten i form av en minskning av fett och sockerkonsumtion i skollunchen och mellanmålet i skolan och på fritids. Dessutom var det att öka den fysiska aktiviteten i skolan med 30 minuter varje dag (utöver idrottslektioner) och att begränsa stillasittande aktiviteter på skol- och fritids tid. Livsmedelsval i hemmet undersöktes med föräldraenkät. Ätattityder utvärderades genom självrapportering. Den fysiska aktiviteten mättes hos 1293 barn med en aktivitetsmätare, (accelerometer), under en veckas tid. Två grupper av barn hade även upprepade mätningar av fysisk aktivitet. Vidare valdes 68 barn utifrån deras BMI till en normalviktig grupp och en grupp med överviktiga/feta barn. Följande tester gjordes: maximalt konditionstest på cykel, kroppssammansättning i röntgen (DEXA), blodtryck och blodprover för att undersöka olika blodfetter, glukos och insulin i blodet.

Resultat: I interventionsskolorna minskade övervikt och fetma från 20.3% till 17.1%. I kontrollskolorna ökade övervikt och fetma från 16.1% till 18.9%. Skillnaden mellan interventions- och kontrollskolor var signifikant ($P<0.05$). Den longitudinella analysen visade ingen skillnad i viktutveckling mellan interventions- och kontrollskolor men en större andel av barnen i interventionsskolorna blev normalviktiga (14%) jämfört med kontrollskolorna (7.5%), $P=0.017$. Resultaten visade ingen skillnad i fysisk aktivitet mellan intervention och kontroll skolor. I slutet på interventionen visades att livsmedelsval i hemmen var hälsosammare i interventionsskolor än kontrollskolor. Det var ingen skillnad mellan intervention och kontrollskolor i rapporterade ätattityder. Resultaten visade en signifikant skillnad i fysisk aktivitet mellan pojkar och flickor i alla åldrar, 6-10 år. Den fysiska aktiviteten sjunker med stigande ålder för både pojkar och flickor. Den fysiska aktiviteten sjunker signifikant från vardagar till helg för både flickor och pojkar med ca 15%. Det är störst skillnad i fysisk aktivitet mellan pojkar och flickor under skol- och fritidstid. Mindre skillnader mellan kön upptäcktes i den fysiska aktivitetsnivån under kvälls- och helgtid. Mönstret är liknande när grupper av inaktiva barn jämförs med aktiva barn. Barn med 2 stycken aktivitetsmätningar visade att den fysiska aktiviteten sjönk signifikant från det första till det andra aktivitetstillfället med 6-7%. Det var en måttlig korrelation mellan det första och andra mättillfället. Resultaten visade även att det var signifikanta skillnader mellan normalviktiga och måttligt överviktiga/feta barn i metabol risk, insulin nivåer och systoliskt blodtryck. Skillnaden mellan grupperna kunde inte förklaras av fysisk aktivitet eller maximal syreupptagningsförmåga. Det visades även ett samband för både fysisk aktivitet och maximal syreupptagningsförmåga med insulinnivåer.

Konklusion: Förändringar över en längre tid i skolan och på fritids med ökad fysisk aktivitet och förbättrad kost har en signifikant effekt på utvecklingen av övervikt och fetma och kan påverka livmedelsval i hemmet. Interventionseffekten berodde sannolikt på hälsosamma ätvanor i skolan, fritids och i hemmet och troligtvis inte på den fysiska aktiviteten eftersom inga skillnader mellan intervention och kontrollskolor i fysisk aktivitet kunde påvisas. Den största skillnaden i fysisk aktivitet mellan pojkar och flickor var under skol- och fritidstid. Barnen var väsentligt mindre fysiskt aktiva när de var lediga under kvällstid och på helger. Upprepade mätningar av fysisk aktivitet visade att det var måttlig korrelation mellan två mättillfällen. Metabola risk faktorer var högre redan bland måttligt överviktiga/feta barn jämfört med normalviktiga barn. Resultaten berodde inte på skillnader i fysisk aktivitet och maximal syreupptagningsförmåga mellan viktgrupperna men fysisk aktivitet och maximal syreupptagningsförmåga visade ett samband med högre insulinnivåer. Måttlig övervikt och fetma visar en skadlig effekt redan hos barn i 8 till 11 års ålder.

LIST OF PUBLICATIONS

I. Physical Activity Patterns Measured by Accelerometry in 6-10 Year Old Children. Medicine and Science in Sports and Exercise. In press.

II. Physical activity in children measured by accelerometry: stability over time. Scandinavian Journal of Medicine and Science in Sports 2009; 19: 30-35.

III. A four-year, cluster randomised controlled childhood obesity prevention study; STOPP. International Journal of Obesity. Online publication date: 17-Mar-2009 doi: 10.1038/ijo.2009.38

IV. Differences in metabolic risk factors between normal weight and overweight 8 to 11 year old children and associations with physical activity and fitness. Submitted.

CONTENTS

LIST OF ABBREVIATIONS

ALSPAC	The Avon longitudinal study of parents and children
AUC	Area under the curve
AW	Actiwatch
BIA	Bioimpedance analysis
BMI	Body mass index
BMIsds	Body mass index standard deviation score
BP	Blood pressure
CRF	Cardiorespiratory fitness
ChEAT	Children's Eating Attitude Test
cpm	Counts per minute
CT	Computer tomography
CV	Coefficient of variation
DELFIA	Dissociation-enhanced lanthanide fluorescence immunoassay
DLW	Doubly labelled water
DEXA	Dual energy X-ray absorptiometry
FAS	Full analysis population
FFM	Fat free mass
FMI	Fat mass index
HDL	High-density lipoprotein
MVPA	Moderate and vigorous physical activity
MRI	Magnetic resonance imaging
NHANES	National health and nutrition examination survey
OC	Observed cases
OGTT	Oral glucose tolerance test
OR	Odds ratio
PAEE	Physical activity energy expenditure
rpm	Revolutions per minute
STOPP	Stockholm obesity prevention project
TG	Triglycerides

FOREWORD

In 2001, the Stockholm Obesity Prevention Project (STOPP) started with schools and children from 10 schools around Stockholm participating. This was the first randomised controlled school-based obesity prevention study ever in Sweden. The project was started as the prevalence of childhood overweight and obesity was rapidly increasing in Sweden and around the world. At that time-point some concern was expressed regarding the young age of the children (6-10 years); whether they were too young to participate in an intervention. In current interventions, however, children are much younger than that.

3135 children have participated in the STOPP-project and both dietary and physical activity changes have been implemented in their schools. Some changes have been more difficult to achieve than others. The staff in the project agrees upon the fact that changes take time, and sometimes a very long time, to achieve. Also, we have come to understand that some of these changes have mostly been difficult for the adults as the children have quite easily and happily adapted to changes in diet and physical activity.

Physical activity in children is of great importance, as it is associated with positive effects on the musculoskeletal health, cardiovascular disease factors, adiposity, as well as self-concept, anxiety, depression and academic performance. The importance of physical activity was recently demonstrated in children where clustered cardiovascular risk was lower among children with higher activity. Furthermore, the prevalence of obesity in children is increasing and physical inactivity may be associated with increased risk of obesity. Taken together, this suggests that promotion of physical activity in childhood does not only influence the current health status but may also have long-term implications.

There is a need for strategies that increase physical activity in children. A deeper understanding of physical activity patterns, associations with metabolic risk factors and its role in obesity prevention may be one step forward, so that we may design effective strategies aimed at increasing physical activity and prevent the development of overweight and obesity in children. Hopefully this thesis will be able to contribute to this comprehensive research area.

1 INTRODUCTION

1.1 PHYSICAL ACTIVITY

Physical activity is defined as "any bodily movement produced by skeletal muscles that results in energy expenditure" [1]. Physical activity is not synonymous to physical exercise (training), which is a subset of physical activity and is defined as " physical activity that is planned, structured and repetitive bodily movement done to improve or maintain one or more components of physical fitness" [1].
Epidemiological research on physical activity began in England in the 1950's, when Jeremy Morris and co-workers found that occupational (habitual) physical activity was related to coronary heart disease [2]. The results showed that bus conductors who spent 90% of their shifts on their feet, had lower rates of coronary heart disease compared to bus drivers, who were mostly sedentary. Since then, the benefits of physical activity has been extensively researched and there are now several evidence based health benefits of physical activity for adults [3] and for children [4].

1.1.1 Health effects of physical activity

In adults, physical activity has been shown to be inversely related to mortality [5] and is associated with cardio-respiratory health, metabolic health, mental health, musculoskeletal health, functional health and cancer [3]. Physical activity in children has been shown to be associated with positive effects on the musculoskeletal health, cardiovascular disease factors, adiposity, as well as self-concept, anxiety, depression and academic performance [4]. Consequently physical activity is effective in preventing diseases. Although many diseases become evident later in life, the origin of diseases commences in early childhood [6] and therefore disease prevention should start at an early age. In addition, physical inactivity may be associated with increased risk of obesity [7].Thus, early promotion of physical activity is of great importance in childhood, as physical activity does not only influence the current health status but may also have long-term implications.

1.1.2 Physical activity assessment

Accurate measures of physical activity are necessary in order to study: relationships with health outcomes, the efficacy of interventions, tracking trends in physical activity and differences in physical activity between populations [8]. The methods of assessing physical activity can be divided into subjective (questionnaires, interviews, and activity diaries) and objective (doubly labelled water, direct observation, pedometry, accelerometry and heart rate monitoring) methods [9]. The assessment of physical activity in children is a challenge and each method has both strengths and limitations [10]. It is important to distinguish between measuring energy expenditure and measuring habitual physical activity. Doubly labelled water (DLW) is the "gold standard" for assessing energy expenditure during free living [9]. The DLW method is expensive and is limited by the inability to provide information on duration, frequency and intensity levels of physical activity [11]. Direct observation is the best method for assessing

physical activity patterns, but the method is time consuming, expensive and dependent on the subjectivity of observers [12]. The self-report method is frequently used due to its low cost and simplicity but it is not recommended to use this method with children under the age of 10 years due to limited accuracy in the assessment of physical activity [10]. Heart rate monitoring has been shown to be a valid and reliable method however factors other than physical activity can influence heart rate during low intensity physical activity [12]. Pedometers are simple to use and inexpensive, but the method is limited by its inability to measure intensity levels of physical activity [9]. Accelerometry is often used in the assessment of physical activity in children and has been shown to be a valid and reliable method [13]. It measures the intensity, frequency and duration of physical activity. One disadvantage of accelerometry is its limited capability to measure movement in the horizontal plane (e.g. cycling and running) and the monitors can not be worn during swimming [12]. In addition, the aspect of differences between measuring energy and habitual physical activity should be taken into consideration when assessing physical activity. There might not be observed differences in physical activity measured by accelerometry expressed in counts per minute between normal weight and overweight children. However, results may be different between those children when measuring energy expenditure for the same physical activity performed.
The three dimensions of physical activity that are often used when assessing physical activity are frequency, duration and intensity.

1.1.3 Variations in physical activity and physical activity patterns

Previous studies using objective measurements of physical activity have suggested that boys are more active than girls [14-20] and gender differences have been shown already in pre-school children [21]. In addition, physical activity has been suggested to decline by, at least from ages 9 to 10 and upwards [22-28], but it is still unclear precisely at what age this decline appears. Furthermore, the patterns of children's physical activity across days [16,17,29,30] and within days [31-34] are less well examined in younger children. This knowledge is important when identifying possible arenas and settings when planning preventive initiatives aimed at increasing children's levels of physical activity.

1.1.4 Tracking and stability of physical activity

Tracking/stability is referred to as "the maintenance of relative rank or position within a group over time" [35]. It is often argued that the promotion of physical activity should start early in life as physical activity seems to track from childhood to adulthood which may influence adult health [36]. Previous studies using objective measurements of physical activity have shown that in 6-9 year old children physical activity seems to track at low to moderate levels [37-39].

1.1.5 Determinants/correlates of physical activity

In a review by Steinbeck, it is shown that physical activity in children is influenced by different components such as age, development stage, gender, socioeconomic status, ethnicity, parental activity and inactivity, prompts to be active, aerobic fitness, obesity and genetic factors [40]. In another review [41] it is suggested that determinants of physical activity in children were: having fewer perceived barriers, having stronger intentions and preferences for physical activity, eating a healthy diet, previous physical activity and having access to facilities and programmes.
It has earlier been shown that children of active mothers are twice as likely to be active and children of active fathers are three times as likely to be active, compared to children of inactive mothers and fathers [42]. Furthermore, Fogelholm and co-authors showed that physical inactivity in parents was a strong predictor of child inactivity [43]. If factors that influence physical activity in children are identified, then effective physical activity interventions can be designed [44].

1.1.6 How much physical activity is needed?

There is no definite conclusion among researchers as to how much physical activity that is needed or what intensity of physical activity that is optimal in order to achieve health benefits among children [45]. In a recent study it was demonstrated that clustered cardiovascular risk was lower among children with higher physical activity [46]. Both the intensity of physical activity and total physical activity have been shown to be associated with cardiovascular risk factors [47] and metabolic risk factors [48].
A higher (vigorous) intensity may have a greater effect on obesity prevention in children, compared to lower intensity physical activities [47,49]. Montgomery et al. suggest that decreasing time spent in sedentary activities is the best way to increase energy expenditure, as the contribution of time spent in moderate and vigorous activity to daily physical activity is limited [50].

1.1.7 Guidelines and recommendations

The most commonly used guidelines recommend children to engage in 60 minutes of accumulated moderate to vigorous physical activity every day [51]. The guidelines are not based on evidence [52] and the amount and type of physical activity is a matter of debate among researchers [53]. Andersen and co-workers [46] suggest that 60 minutes of physical activity every day is insufficient and that the recommendation should be increased to 90 minutes per day in order to prevent clustering of cardiovascular disease risk factors.

1.1.8 Are children active enough?

Previous studies that have examined whether children are active enough according to guidelines and recommendations, have obtained varying results [14,18,54,55]. Dencker et al. showed that all Swedish 8 to 11-year-olds reached physical activity recommendations and that is in accordance with data from the European Youth Heart Study where the majority of the children reached the recommendations [18]. On the contrary, Riddoch et al. showed that only 2.5% of 11-year-olds reached the physical activity recommendations [55]. Different cut points for defining intensity when using accelerometers contribute to the difficulty of comparing results between studies [55]. The differences in results may also be explained by, different physical activity levels between countries.

1.1.9 Secular trends in physical activity

A popular perception is that children are less physically active nowadays than they were in past times, but there is little evidence to support this perception [45]. Diversity in methodological approaches when assessing physical activity makes it very difficult to

interpret and compare results between studies [45]. Further, there is an absence of baseline data [56]. However, even though there is an uncertainty about declining physical activity levels there is evidence to support the fact that active transport, physical education classes in schools and participation in organised sports are declining among children in many countries [56]. In a review by Biddle et al. it is suggested that the total media time over recent decades appears remarkably stable, although the content of the media use will have changed [41]. However, that result is probably difficult to generalise for all children since there is most certainly a great difference and variety between countries. Interestingly, a recent study (n=4688) show that children who walk to school are more active during the week and therefore promotion of active travelling might be an effective strategy in increasing physical activity in children [57].
Although speculative, the absence of children playing outdoors in their spare time and the fact that many children are being driven to schools and other activities, in combination with the increase in childhood obesity, makes it easy to draw the conclusion that children are less physically active nowadays. Also, “activity toxic” environments are emerging and in Sweden many pre-schools and schools have now changed outdoor play areas and the school environment, for safety reasons, but have still not created good alternatives for the children in order to stimulate play and physical activity.

1.2 CHILDHOOD OVERWEIGHT AND OBESITY

Childhood overweight and obesity are emerging health problems in all western countries and also in urban areas in developing countries [58,59].
In Sweden the prevalence of overweight and obesity has been rapidly increasing [60,61]. Approximately15-25% of Swedish ten-year-old children are overweight or obese [62,63]. Recent evidence suggest that among 10-year-old children, in urban Sweden, the obesity epidemic may be levelling off and may possibly be reversing among girls [64]. The results are supported by data from another area in Sweden (Stockholm), showing that the prevalence of overweight and obesity was stable between 1999 and 2003 [65]. Further, the results showed that the prevalence of obesity was higher in less affluent areas.

1.2.1 Definition of childhood overweight and obesity

The definition of overweight and obesity can be defined as an excess of body fat [66]. Body mass index (BMI) is calculated as weight (kg) divided by height (m) squared. The World Health Organisation defines overweight in adults as a BMI equal to or more than 25 ($\geq$25 kg·m^{-2}) and obesity as a BMI equal to or more than 30 ($\geq$30 kg·m^{-2}) [67]. When defining childhood overweight and obesity, BMI values are often used as standard deviation scores (SD) [40]. The International Obesity Task Force has published gender and age specific cut-off points for children and adolescents between the ages of 2 and 18 years so that the BMI in childhood can be related to BMI in adulthood (Cole 2000).

1.2.2 Aetiology

Although the causes of obesity are not fully understood, an imbalance of energy intake exceeding energy expenditure will result in the development of obesity [66]. Childhood obesity is multi-factorial, and determinants of obesity include genetics, biology, behaviour and the child's environment [68]. However, it is plausible that lifestyle changes explain the rapid increase in the prevalence of overweight and obesity in most western countries in the past 25 years [69]. The most important factors explaining these changes are related to altered eating habits and reduced physical activity [69].

1.2.3 Consequences of childhood overweight and obesity

Childhood obesity affects self-esteem and increases the risk of future diabetes, cardiovascular disease and malignancies [70-74]. Thus, childhood obesity is a major threat to public health and may reduce life expectancy [74-77]. Importantly, obesity in childhood is an independent risk factor for obesity in adulthood [78]. Guo and Chumlea report that the risk was up to 80% of becoming obese in adulthood (at the age of 35 years) for the children being obese in childhood (>9 years) [79].

1.2.4 Body composition assessment

The only direct method to measure body fat is to make a cadaver analysis and therefore indirect methods are available to provide estimations of body fat mass and fat free mass [80]. Such methods include densitometry, magnetic resonance imaging (MRI), computer tomography (CT), bioimpedance analysis (BIA) and dual energy X-ray absorptiometry (DXA). In field studies BMI, waist circumference and skinfold thickness measurements are commonly used. It is important to bear in mind that these methods are predictors and only proved approximate measurements of body fat. The use of BMI is supported in groups of children but caution should be taken at an individual level [81,82]. The use of waist circumference measurement is increasing, as central obesity may be more associated with health risks such as the metabolic syndrome compared to total body fat [83].

1.3 CARDIO-RESPIRATORY FITNESS

Physical fitness is defined as "a set of attributes that individuals possess or achieve that relates to their ability to perform physical activity" [1]. Cardio-respiratory fitness is one component of health related fitness and reflects the ability of the cardiovascular and the respiratory systems to supply oxygen to the working muscles during exercise [84]. Cardio-respiratory fitness has been found to be inversely related to clustered metabolic risk, cardiovascular and metabolic risk factors in children [48,85-87].
Cardio-respiratory fitness can be assessed by measuring $V0_{2max}$ during indirect calorimetry in a maximal test or estimated in maximal or sub-maximal tests. It was recently shown that cardio-respiratory fitness has decreased between 1998-2004 in a large cross-sectional study with 9 to 11-year-olds [88].

1.4 METABOLIC RISK FACTORS

There is an increased recognition of the metabolic syndrome in children [89]. The metabolic syndrome may be characterised by the clustering of three or more of the following risk factors: hypertension, hyperglycemia, elevated levels of triglycerides (TG), low levels of high-density lipoprotein (HDL-C) and adiposity [90]. The International Diabetes Federation has recently suggested a unified definition for the metabolic syndrome in children [91]. The prevalence of the metabolic syndrome in youth varies between 0.2% and 12% [90,92].

Low physical activity and low cardio-respiratory fitness are associated with an increased risk of developing the metabolic syndrome in adults [93] but there is less evidence for the associations between physical activity, cardio-respiratory fitness and metabolic risk factors in children. The contribution of both environmental and genetic factors to physical activity levels, cardio-respiratory fitness and metabolic risk factors might add further complexity when analysing associations hereinbefore. Intervention studies are therefore warranted to examine whether associations may be modifiable. Earlier studies have shown that markers of insulin resistance, hypertension, hyperlipedemia, and clustered metabolic risk have been inversely associated with objectively measured physical activity in healthy children [48,94,95]. Further, cardio-respiratory fitness has been found in a few studies to be inversely related to clustered metabolic risk and metabolic risk factors in children [48,85-87]. Of note, the presence of obesity and metabolic risk factors during childhood appear to predict the development of the metabolic syndrome later in life [96-98].

1.5 OBESITY INTERVENTIONS

Childhood obesity is a major health problem. Still, only a limited number of intervention studies have been conducted [99]. Interventions in childhood may be effective, as children may be more flexible in changing lifestyle behaviours than adults [40]. Also, interventions during childhood are important, as the adiposity rebound in pre-puberty is a period in childhood where there is an increased risk for the development of obesity [40]. School-based interventions are of great benefit, as all children can be reached and school-based programmes are cost-effective [100].

Previous preventive efforts have shown a limited success in reducing the prevalence of childhood obesity in school-based interventions and results are inconclusive [100-103]. Most intervention studies include both physical activity and dietary changes and there is still insufficient evidence to compare the effectiveness between diet and physical activity interventions [101]. In the most recent systematic review by Brown et al. differences in body mass index between intervention and control schools were studied showing efficacy in 1 of 3 diet studies, 5 of 15 physical activity studies and in 9 of 20 combined diet and physical activity studies. Findings suggest that interventions may be more effective in younger children and particularly in girls [101]. Further, it is suggested that interventions might have a better effect if designed differently for boys and girls and there is a trend indicating that structural and environmental interventions may be more effective for boys whereas interventions grounded in social learning seem to be more effective for girls [104].Overall, previous intervention studies show modest changes in behaviours and mixed results with indicators of obesity, confirming that it is very difficult to succeed in reducing childhood overweight and obesity [100].

1.6 STRATEGIES AROUND THE GLOBE

The rising prevalence of childhood obesity has resulted in government initiatives and industry responses in many countries [105]. Initiatives from governments include implementation of after-school activity programmes, walking school buses, removal of vending machines, nutritional labelling of food products and modification of school lunches [105]. Initiatives from the industry range from changes in fast food offerings to striving to achieve an increase in the fruit and vegetable intake and commercial fitness industry programmes targeted to children [105].

2 AIMS OF THE THESIS

- To study differences in patterns of objectively measured physical activity among weekdays and weekend days and among different time periods during the day and, further, to examine how these patterns are influenced by age and gender, in a large sample of 6 to 10-year-old Swedish children (Study I).

- To examine the stability of physical activity in children (Study II).

- To evaluate the efficacy of a school and after school care based obesity prevention programme, STOPP, focused on healthy eating, including modification of school lunches and afternoon snacks, increased physical activity during school time and a reduction of sedentary activities during time spent in after school care (Study III).

- To study differences in single metabolic risk factors and clustered metabolic risk in groups of normal weight and moderately overweight children and, further, to examine whether differences in metabolic risk can be explained by physical activity and fitness (Study IV).

3 MATERIALS AND METHODS

The STOPP study was designed as a school-based intervention study spanning 4 school years, conducted between August 2001 and June 2005. Ten primary schools including children between 6 to 10 years of age within the Stockholm county area were selected. The social and ethnic background was similar in control and intervention schools. The proportion of parents categorised as immigrants varied between 5%-10% (range) in both intervention and control schools. The proportion of children living with two parents varied between 63%-77% in intervention and 63%-80% in control schools, low-income households between 8%-22% in intervention and 7%-22% in control schools and parents reporting an academic level of education (higher than upper secondary school) between 23%-46% in intervention and 26%-46% in control schools. Five of the selected schools were thereafter randomised to intervention and five schools to control. All children participated in the study until the end of their fourth school year, i.e. until the age of 9-10 years. Thus, the children who entered the study during their first school year in August 2001 participated in the programme for 4 years, whereas children who started school in subsequent years participated in the programme for shorter time periods.

3.1 STUDY DESIGN AND PARTICIPANTS

The whole cohort of children is represented in Study I and III. In Study II and IV, two different sub-groups of children are participating. Participation during the intervention is shown in Figure 1.

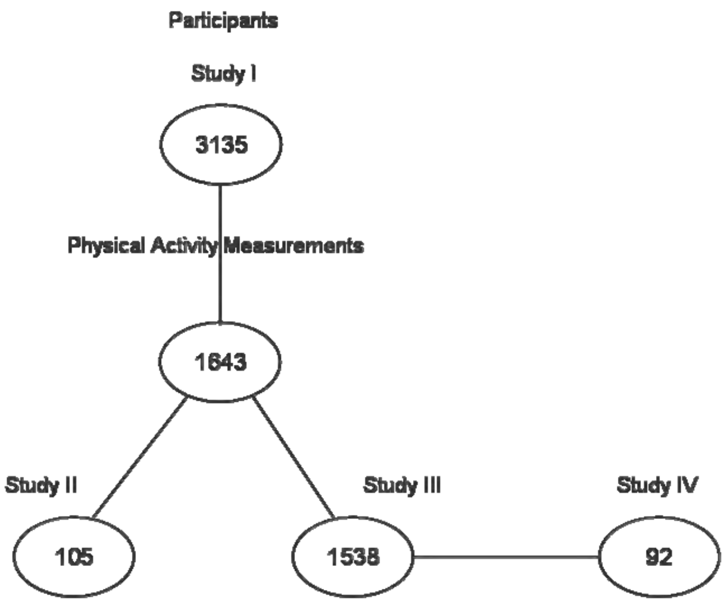


Figure 1. Number of participants in Study I - IV.

Study III

In total, 1670 and 1465 children (51% boys) aged 6-10 years, were included into the intervention and control regimen between 2001 and 2004 (Figure 2). 92% to 100% of the children in the intervention schools and 90% to 100% of the children in the control schools were entered into the study and participated in at least one occasion of weight and height assessment.

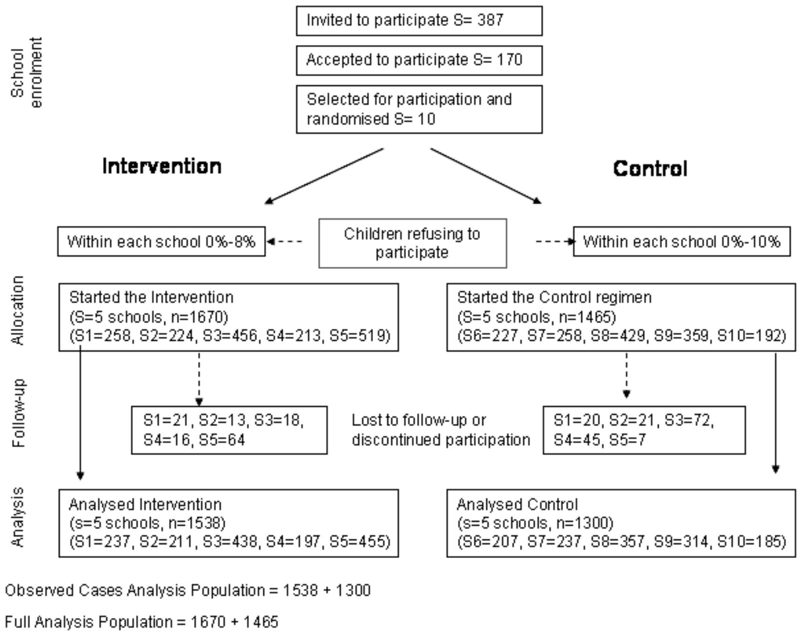


Figure 2. Children in the STOPP study through each stage of the trial, i.e. enrolment, allocation, follow-up and analysis

1538 children in the intervention and 1300 children in the control schools had their heights and weights measured on least at two occasions during the study and were defined as the observed cases (OC) analysis population. 132 children from intervention schools and 165 children from control schools only participated in one assessment. All children whose height and weight were measured at least once are defined as the full analysis population, (FAS).

Study I

A total of 1538 children from the STOPP-study were included. Of these, 245 (16 %) children were excluded due to invalid physical activity registrations or technical failures with activity monitors. Thus, 1293 children had valid physical activity data (653 girls and 640 boys) and were included in the evaluation. Each child included in this study was measured once. The children were equally distributed between intervention (n=653) and control schools (n=640). Since no differences in physical activity levels between intervention and control schools were observed, all children were pooled.

Study II
A total of 105 children from the STOPP-group (Study I) provided repeated measurements of physical activity and were included in the study. Eight children were excluded (8 %), seven children due to invalid registrations in either of the physical activity assessments and one child with only 63 days between the two assessments. Thus, 92 children were included in the study.

Study IV
The study includes 68 children who previously participated in the STOPP-project. Children aged 8 to 11 years were selected from the group of children in the STOPP-project that had measurements of physical activity (Study I). The children were selected based on their BMI levels. This was done in order to create two groups of normal weight (n=39) and overweight and obese children (n=24/n=5). Ninety-two children agreed to re-test their weekly physical activity and 68 children agreed to participate in the study.

3.2 STOPP INTERVENTION

The aim was for the intervention to be financed within the resources of the ordinary school budget. The activities of the research staff were restricted to documentation of school activities, to perform measurements of physical activity, height and weight and also to encourage the school and after school care centre staff to carry out suggested changes.
The main focus of the intervention was to change the school environment rather than provide healthy life style education, although the school and after school care centre staff were encouraged to emphasise the importance of healthy eating and physical activity.
Most Swedish 6-10 year old children attend after school care centres during after school hours. The centres are usually open until 6 pm. More than 90% of the participating children ate their lunch at school (school lunch is free for all children in the Swedish school system) and had an afternoon snack at the after school care centre, i.e., approximately 30-35% of the children's weekly meals were provided in a setting possible to control in the prevention program.

3.2.1 Physical activity intervention

The intervention aimed to increase the amount of physical activity by 30 minutes per child and day. Therefore, an additional 30 minutes of daily physical activity was integrated into the regular school curriculum and facilitated by the class teachers. To reduce sedentary behaviour, children were not allowed to bring toys that might increase this behaviour, such as hand held computer games, to schools and after school care centres. The maximum time spent playing computer games at the after school care centres was restricted to 30 minutes per child and day.

3.2.2 Dietary intervention; school lunch and afternoon snack

The teachers were instructed to encourage the children to increase the intake of vegetables when having the school lunch. To facilitate this, all intervention schools had agreed to offer a variety of vegetables and the food was arranged so that the children first served themselves vegetables and thereafter the main course. White bread was substituted with whole grain bread or similar products including a high amount of dietary fibres. The sugar content of the school lunches and the afternoon snacks was reduced, through strategies such as replacing fruit yogurt with plain yogurt and eliminating fruit juices, soft drinks, lemonades and desserts. Whole fat (3% fat content) or medium fat (1.5% fat content) milk was substituted by skimmed milk (0.5% fat) and low fat butter, cheese and yoghurt were provided. Sandwich ingredients were required to be low-fat.

3.2.3 Other aspects on food intake

Intervention schools were encouraged to eliminate sweets, sweet buns and ice cream in connection with festivities. When celebrating birthdays parents were asked not to provide these products at schools and after school care centres. Furthermore, parents of the children in the intervention schools were instructed not to supply sweetened drinks, sweets and other unhealthy products in the packed lunch during school excursions and sports days.

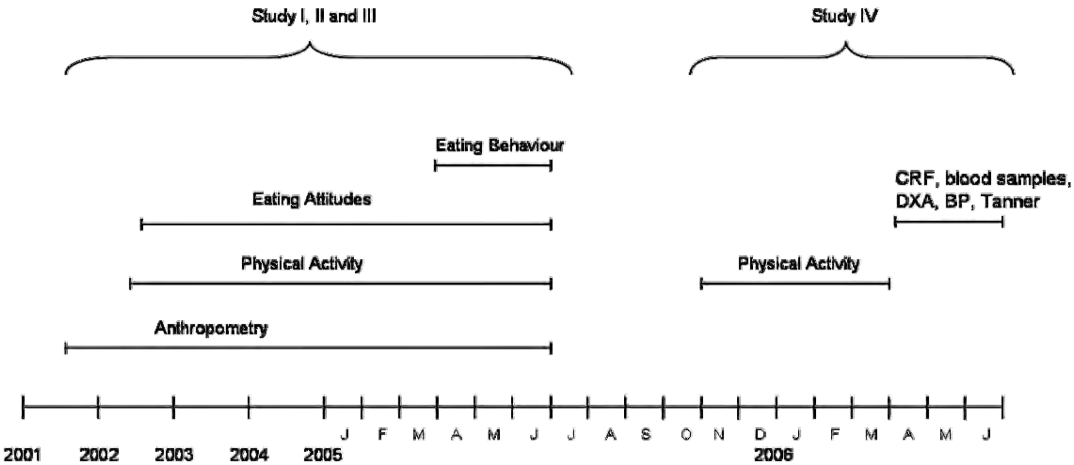
3.2.4 Awareness intervention

A STOPP newsletter was distributed to parents and school staff of intervention schools twice annually aimed at increasing the awareness of the intervention. Furthermore, the research staff had meetings with the school personnel once every term. These meetings were also aimed at increasing the awareness of the intervention. School nurses received education in obesity related problems.

Compliance with the STOPP concept was checked regularly, when the research staff visited schools during lunches, after school care activities and sports days. Furthermore, the STOPP staff also performed random, unannounced, school visits. Deviations were documented and discussed with the school staff and the headmasters. All control schools continued their normal curriculum and none of the intervention activities were performed, except for yearly measurements of height, weight and physical activity. However, the parents in the control schools received information regarding the aim but not the content of the study.

3.3 MEASUREMENTS

A time table of the different measurements is shown in Figure 3.



3.3.1 Anthropometry

Weight and height measures were performed in all children at the beginning of the school year in the autumn. For children who finished fourth grade and therefore left the study, weight and height were also measured at the end of the school year (May-June). On completion of the study all children still participating in the study were assessed for efficacy, in May-June 2005.

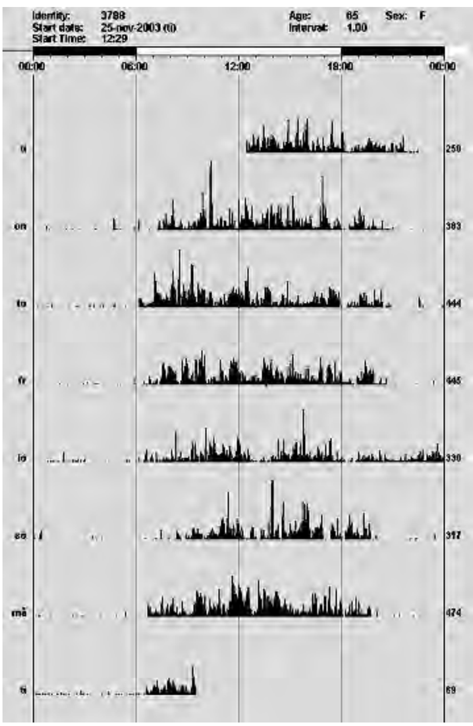
Height and weight were measured using standard clinical procedures with a transportable Harpenden Stadiometer and a digital scale (Tanita BWB 800S, Tanita, Tokyo, Japan). Height was measured to the nearest 0.1 cm and weight to the nearest 0.1 kg. Body mass index (BMI) was calculated as weight (kg) divided by height (m) squared. Body mass index standard deviation score (BMIsds) was calculated according to a reference standard [106]. Overweight and obesity were defined according to the International Obesity Task Force recommendations [107]. All the children were measured after 9 am in the morning but before lunch, wearing light underwear and without shoes. Trained research assistants performed all anthropometric measurements.

3.3.2 Physical activity

Physical activity was assessed using an accelerometer, Actiwatch® (AW) (model 4, Cambridge Neurotechnology Ltd, Cambridge, UK). The accelerometer is small, lightweight and worn on the non-dominant wrist like a watch.

The children were instructed to wear the AW for the whole week, except while swimming and bathing. The accelerometers were distributed individually to each child on a weekly basis, evenly across gender and age groups and between intervention and

control schools. Twenty children were randomly selected and measured every school week. Physical activity was assessed for 7 consecutive days. The accelerometers were collected and re-distributed every Tuesday. We also categorised children gender specifically into tertiles of low, medium and high activity levels, based on their mean total activity counts.
Physical activity was calculated as total counts divided with the total recorded time and expressed as counts per minute (cpm). Total physical activity (between 8 am-9 pm) was calculated over the 7-day period. Overall mean physical activity was also compared among weekdays and weekends (between 8am-9pm) and among different time periods of the day. School time was defined as 8am-1.30pm, after school care time as between 1.30pm and 4pm, and evening time between 4pm and 9pm. We only included time periods where more than 80% of the time included registered movement data in our analyses. All children (n=1293) who provided at least 600 minutes of activity registration per day for a minimum of 4 days, including one weekend day were included in the analyses. In accordance with previous studies using accelerometry [18] data were excluded from the analyses if sequences during the waking hours indicated 10 or more consecutive zero counts, assuming that the monitor had then been removed from the body. The epoch length was set to 1 minute.
The accelerometers were calibrated in a mechanical shaker every 6 weeks and recordings were omitted if values were out of range (>5%) compared to their initial calibration data. In such cases the accelerometer was sent to the manufacturer for calibration or repair. All individual physical activity recordings were checked manually.



Actogram

Validity and reliability of the Actiwatch

The validity of the AW monitor placed at the hip or lower leg has previously been examined in children with correlation coefficients ranging from 0.66 to 0.89 [108,109]. The wrist-worn AW has been found to be feasible for long-term studies of physical activity in children [110]. We have recently compared Actiwatch output against physical activity energy expenditure (PAEE) measured by indirect calorimetry in 8 to 10-year-old children. Actiwatch counts explained 86% of the variance in PAEE during various free-living activities (unpublished results).

Most previous studies have used accelerometers worn on the hip. Differences in placement may affect the outcome of accelerometer data. Therefore, we have compared the output from the AW with another frequently used hip mounted accelerometer (ActiGraph). A group of children (n=44) similar in age to our study participants wore both monitors during seven consecutive days. The outcome from the AW was significantly correlated with activity counts from the Actigraph ($r=0.68$, $p<0.001$), without any difference in mean counts between groups ($p=0.48$) (unpublished results). A significant negative correlation ($r=-0.66$, $P<0.001$) was observed between the difference of AW and Actigraph counts and the mean of the methods in a Bland Altman plot, resulting in lower AW levels in highly active children and consequently higher AW levels in low-active children compared to Actigraph, suggesting the output from the two different instruments are not comparable.

The coefficient of variation (CV) for the intra-instrument repeatability of the AW devices was 1.72% on 180 revolutions per minute (rpm), 0.94% on 240 rpm, 1.17% on 280 rpm and 0.72% on 320 rpm. The CV for the inter-instrument reliability on the four intensities ranged between 6.6 – 8.4% (unpublished data).

Strengths and limitations of the Actiwatch

Although speculative, one possible advantage of the AW compared to hip worn accelerometers is that it is easier to achieve a high compliance with a wrist-worn accelerometer. The children rarely took the AW off, as it is not obstructing their natural way of living, and thereby it also reduces the risk of the children forgetting to put the monitor back on.

It is important to realise that accelerometers have limitations when it comes to measuring activities with limited vertical movements, such as cycling. Also, the devices need to be removed when performing water activities, which may contribute to an underestimation of physical activity. Furthermore, there is a possibility that physical activity may be overestimated when acceleration is increased by external forces, such as horseback riding or riding a car on a bumpy road. Accelerometer counts may be affected by the length of the body segment where it is mounted. However, we found no correlation between height and AW activity counts when a group of 8 to 10-year-old children (n=22) measured physical activity and performed standardised activities of different intensities.

3.3.3 Eating habits

At the end of the study a questionnaire regarding eating habits at home was distributed by the school staff to the parents of all children in the third and fourth grades. The questionnaire consists of 14 multiple choice questions and assessed the frequency of

food items served at home, with the following alternatives; every day, several times a week, 1-2 times a week, rarely/never. Overall, 692 of 770 families (89.9%) filled out the questionnaire, 91% in intervention and 87% in control schools, after one reminder letter.
The questionnaire was categorised into eight domains, dairy products (milk, butter and cheese), cereals, bread, fast food (hamburgers, pizzas, and French fries), crisps/nuts (crisps, peanuts and pop corn), sweet products (ice-cream, buns, cookies and sweets), drinks (soft drinks, syrup, juice and sweet milk drinks) and fruit and vegetables. Before analyses, all domains were dichotomised into healthy and unhealthy levels of food consumption. The unhealthy choices in the dairy products were defined as whole fat milk (3% fat), butter (>40% fat) and cheese (24-40% fat) every day or several times a week. Further, unhealthy choices included sweetened cereals or white bread, fast food products and sweetened drinks, when being selected every day or several times a week. The criteria for an unhealthy/energy dense/high fat choice for crisps/nuts and sweet products was when the products were being selected once or twice a week, in addition to every day and several times a week. The consumption of fruits and vegetables was categorised as unhealthy if consumed 1-2 times per week, a few times per week, or never.
Breakfast and dinner eating habits were categorised into a weekly breakfast and dinner score respectively. The score was derived from the number of days, with intake of breakfast and dinner multiplied by the number of family members that was present during the meal. Number of family members was scored as: at least one parent (=3), a sibling (=2) and alone (=1). The number of days of intake were scored 0-2 (=1), 3-5 (=2) and 6-7 (=3). The total score ranges from 0-9, with higher scores indicating "better" eating habits. The level of parental educational background was divided into high (3 years at upper secondary school or more) and low (less than 3 years at upper secondary school) and was used as an indicator of socioeconomic status.

3.3.4 Eating attitudes

Eating attitudes were assessed by a Swedish version of ChEAT (Children's Eating Attitude Test) [111,112]. All children were requested by the teachers to fill in the ChEAT questionnaire before terminating the project in grade 4, (n=1750), i.e., when the children were 9-10 years old. The questionnaire was administered by teachers according to written instructions. In total, 78 % questionnaires were returned (n=1368). Questionnaires with missing values were omitted and complete questionnaires were received for 70% of the children (n=1227).

3.3.5 Body composition

Body composition was assessed by dual-energy x-ray absorptiometry (DXA) (Lunar Prodigy Advance, GE Healthcare, Madison, Massachusetts, USA). Fat mass index (FMI) was calculated as fat mass (kg) divided by height (m) squared. Fat free mass (FFM) was defined as the fat-free soft tissue, excluding bone mineral content from the scans. The children were instructed not to perform any strenuous physical activity the day before the examination. The same technician performed all the scans using standard clinical procedures.

3.3.6 Sexual maturation

Sexual maturation was determined by a paediatrician according to Tanner [113]. Genital development in boys and breast development in girls were used for pubertal classification.

3.3.7 Blood pressure

The systolic and diastolic blood pressures (BP) were measured in the sitting position with a mercury sphygmomanometer with a standard pressure correctly sized cuff on the left arm. The blood pressure was measured in duplicates. If the readings differed more than 5 mm Hg a third measurement was taken and the mean of the two closest readings was used. The same experienced person performed all the measurements.

3.3.8 Biochemistry

Blood samples were drawn at the hospital after an overnight fast. Fasting was confirmed by the child before collecting the blood. An oral glucose tolerance test (OGTT) (1.75 g glucose/kg body weight, maximum of 75g) was performed with blood samples being collected for glucose and insulin at baseline and then at 30, 60, 90 and 120 minutes. Glucose was analysed with the hexokinase method at the certified laboratory at the Department of Clinical Chemistry at Karolinska University Hospital. Similarly, HDL-cholesterol (HDL) and triglycerides (TG) were analysed with enzymatic methods. Fasting and post glucose load insulin was analysed using DELFIA, dissociation-enhanced lanthanide fluorescence immunoassay (PerkinElmer, Massachusetts, USA). The insulin blood samples were stored at -80º C before analysis. All other blood samples were analysed immediately. The area under the curve (AUC) was calculated as the means from the values from the five time points multiplied by the total time for both glucose and insulin.

3.3.9 Cardiorespiratory fitness

Cardiorespiratory fitness (CRF) was assessed on an electronically braked ergometer cycle (Monark 839E, Varberg, Sweden), according to the Hansen protocol [114]. The initial workloads were 20 W for children weighing less than 30 kg and 25 W for children weighing 30 kg or more. Heart rate was recorded continuously throughout the test (Polar Vantage, Finland). The workloads were increased every third minute until exhaustion, defined as a heart rate of 185 beats per minute or more, failure in being able to pedal at least 30 revolutions per minute and a subjective judgement by the observer that the child could no longer continue, even after verbal encouragement. Cardio-respiratory fitness was expressed as watts per kilogram fat-free mass (fat-free soft tissue). Cardio-respiratory fitness estimated for this protocol is highly correlated (r=0.92) with maximal oxygen uptake measured by indirect calorimetry in 9-year-old children [115]. All tests were performed by the same researcher.

3.3.10 Clustered metabolic risk score

A clustered metabolic risk score based on insulin, glucose, HDL, TG and BP was computed in accordance with earlier studies [19,48,95,116]. The variables were standardised to a z-score for each of the metabolic outcome measures, i.e. as the number of SD units from the sample mean [z = (observed value-sample mean)/standard deviation]. The z-score for HDL was multiplied with -1 to indicate higher metabolic risk with increasing value, as the other measures already had such structure. Systolic and diastolic blood pressures were combined using the mean of the two z-scores for systolic and diastolic blood pressures. The clustered metabolic risk score was calculated as the mean of five z-scores (insulin/AUC, glucose/AUC, TG, HDL and BP). Earlier studies have used fasting values of the insulin and glucose measurements. In this study the measurements of insulin and glucose have been performed with different methods and therefore a modified metabolic risk score has been used.

3.4 STATISTICAL ANALYSES

The statistical methods that have been used in this thesis are presented in Table 1.

Table 1. Statistical methods used in Studies I-IV.

	Study I	Study II	Study III	Study IV
Descriptive statistics	x	x	x	x
Student's t-test	x	x		x
Analysis of variance ANOVA	x		x	x
Multiple regression		x		
Pearson's correlation coefficient	x	x		x
Mann Whitney U-test			x	
Logistic regression analysis			x	

4 RESULTS

The main results are presented separately for Studies I-IV.

4.1 STUDY I

The results show that boys were 8% more active than girls (P<0.001). Mean weekly physical activity was significantly higher in boys compared to girls (F=46.50, P<0.001) in all age groups, ranging from 7% to 13%. Further, mean physical activity was inversely related to age (F=10.34, P<0.001) independent of gender (Figure 4). No interaction effect could be detected between gender and age (F= 1.64, P=0.18). Post hoc tests revealed that mean weekly physical activity was 9% higher in 6-year-old girls and boys compared to 9-year-old girls and boys (P<0.001).

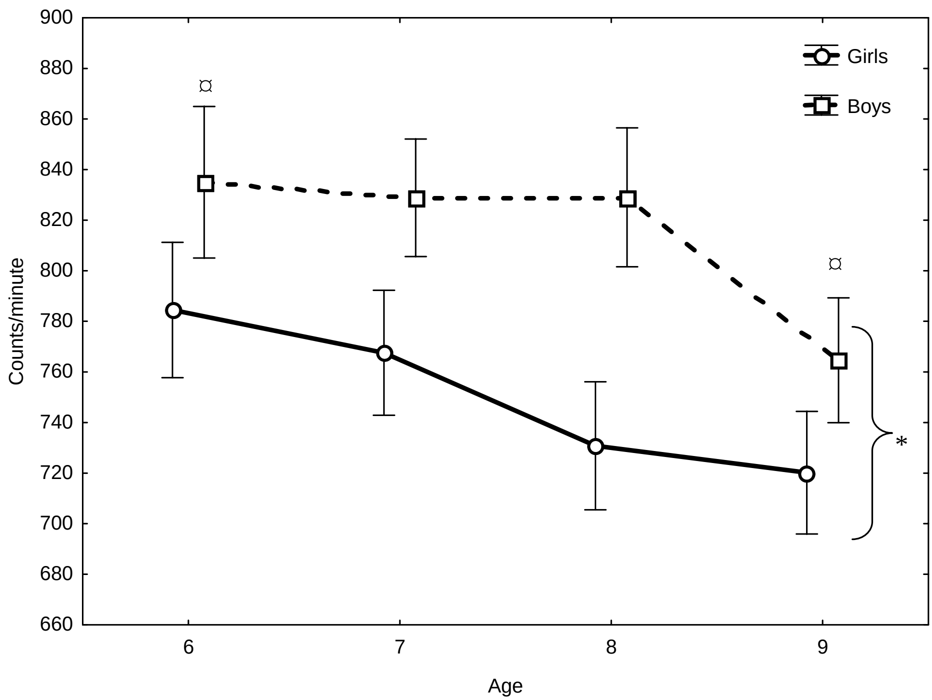


Figure 4. Cross-sectional differences in total physical activity (8 am –9 pm) by gender and age. * P<0.001 between gender (all age groups together). ¤ P<0.001 between ages (girls and boys together).

Mean daily physical activity was lower across ages for weekdays (F=9.86, P<0.001) and weekends (F=6.82, P<0.001) respectively. No interaction effect could be statistically demonstrated between gender and age during weekdays (F= 1.65, P=0.18) and during weekends (F=0.78, P=0.51).
A significant interaction effect across days and gender (F=3.31, P=0.005) was observed where the gender difference in mean daily physical activity was greater during the days at the beginning, compared to days at the end of the week (Figure 5).

Further, a significant interaction effect for mean daily physical activity between weekdays-weekends and gender was observed (F=7.0, P=0.008). Mean daily physical activity declined from weekdays to weekend days in boys (post hoc test: P=0.001) and in girls (P=0.001) and this decline was more pronounced in boys. A mean difference between weekdays and weekend days of 17% in boys and 15% in girls was observed. There was no interaction effect between weekdays-weekends and age (F=0.68, P=0.41).

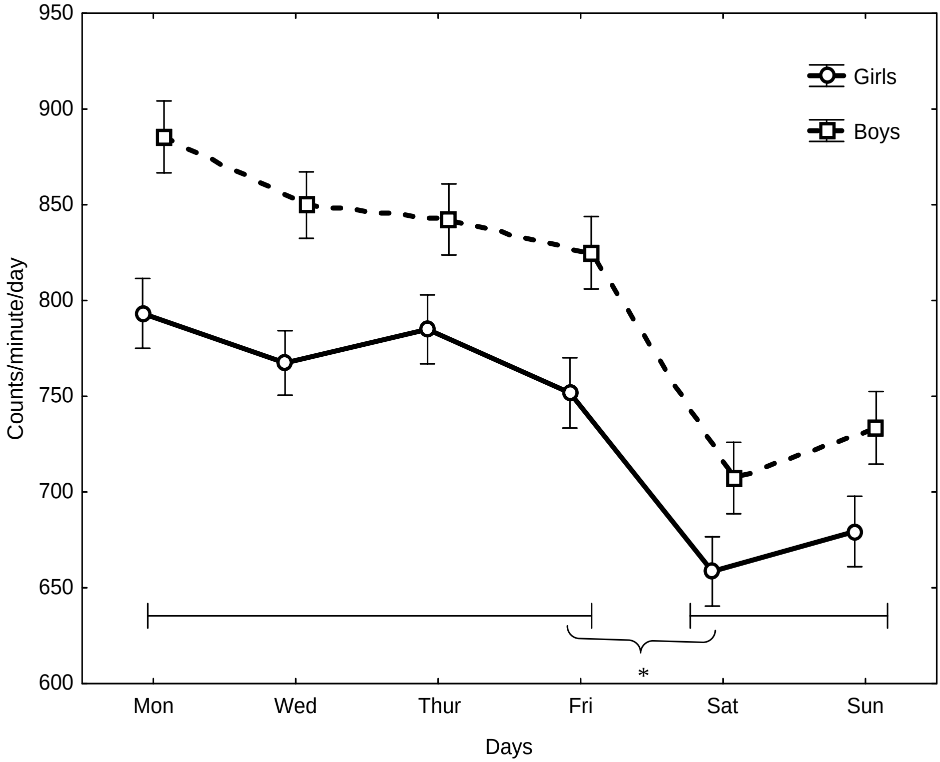


Figure 5. Weekly pattern of total physical activity (8 am-9 pm) in boys and girls. *P<0.001 between weekdays and weekends (girls and boys together).

The decline in mean daily physical activity among weekdays and weekends and activity groups was similar when categorising children into tertiles of overall physical activity (19% in low, 13% in medium and 14% in high activity groups for girls and 24%, 18% and 13% for boys respectively). No interaction effect was observed among weekdays-weekends, gender and activity groups (F=1.94, P=0.14).

A significant three-way interaction effect across gender, time periods and weekdays-weekends was observed for mean time period physical activity (F=16.07, P<0.001) (Figure 6). Post hoc tests showed that across age groups, boys were approximately 13% more physically active than girls during school time (i.e. between 8am and 1.30pm, P<0.001) as well as during after school care time (i.e. 1.30pm to 4pm, P<0.001). Further, there was no difference between boys and girls in activity levels between 4pm

and 9pm on weekdays. During weekends there was a significant difference between boys and girls for all examined time periods 8am-1.30pm (P<0.001), 1.30pm-4pm, (P=0.02) and 4pm-9pm, (P=0.003). Post hoc test of mean physical activity also showed that boys (P<0.001) and girls (P<0.001) were significantly more active during after school care time compared to school time on weekdays.
There was no statistically demonstrated difference (F=0.82, P=0.48) in mean daily physical activity across the number of days (4-7 days) of physical activity measurement.

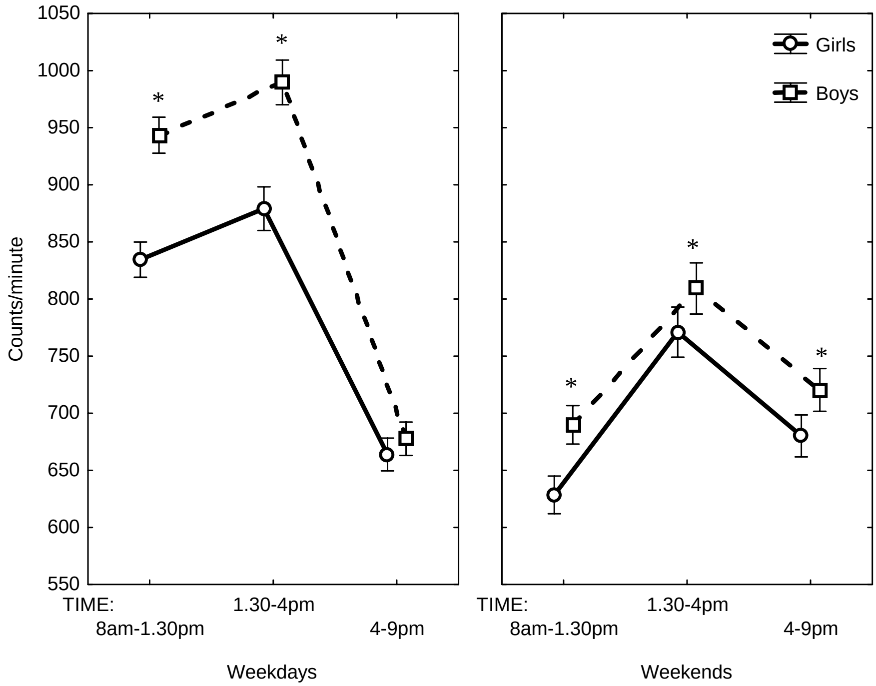


Figure 6. Physical activity at different time periods during the day, weekdays and weekends in boys and girls. *P<0.001, **P<0.01, ***P<0.05 between gender.

4.2 STUDY II

The results showed that the mean physical activity decreased by approximately 6% in children between examinations (795 cpm vs 751 cpm, P=0.005). Mean physical activity during weekdays decreased from 827 cpm to 781 (P=0.005) and from 724 cpm to 687 cpm (P=0.09) on weekends, Table 2.

Table 2. Descriptive data of 41 boys and 56 girls at baseline and follow-up time, (SD).

	Baseline assessment		**Follow-up assessment**	
Age (yrs)	7.5	(0.92)	9	(0.92)
Weight (kg)	27.3	(6.2)	32.8	(7.7)
Height (cm)	125.8	(0.08)	135.2	(0.08)
BMI SDS	1.02	(1.69)	1.09	(1.63)
Mean of recorded days	6.5	(0.63)	6.5	(0.66)
Physical activity mean (cpm)	795	(174)	751	(159)
Physical activity mean (cpm) Weekdays	827	(184)	781	(158)
Physical activity mean (cpm) Weekends	724	(201)	687	(193)

Baseline physical activity was significantly correlated with physical activity at follow-up (r=0.59, P<0.001). The relationship was stronger for boys (r=0.72, P<0.001) than for girls (r=0.51, P<0.001).
We thereafter divided the group in tertiles based on the children's baseline activity levels. The correlation between physical activity at baseline and follow-up was stronger in the group with the highest physical activity (r=0.74, P<0.001) compared to the medium group (r=0.44, P=0.01) and the low physical activity group (r=0.55, P=0.001).

Physical activity at baseline (P<0.001) and seasons contributed significantly to the explained variance in activity at follow-up (R^2=0.46, Table 3). Activity measurements during the dark season followed by measurements in the light season and light to light season measurements were significantly higher than baseline measurements made in the light season with follow-up measurements during the dark season (P=0.001 and P=0.02) when the difference between mean physical activity for each season was calculated. Gender, age, BMIsds and follow-up time did not significantly contribute to the explained variation in physical activity at follow-up.

Table 3. Multiple linear regression analysis between the dependent variable, physical activity at follow-up and the independent variables: physical activity at baseline, BMI SDS, age, follow-up time, gender and seasons measured dark-dark, dark-light and light-light.
***b* = regression coefficient (slope); R^2 = amount of explanation.**

	R^2=0.46			
n=97	**b**	**95% CI**	**p-value**	**ΔR^2 ***
Physical activity at baseline	0.558	0.405, 0.712	<0.001	0.314
BMI SDS	-10.185	-25.209, 4.839	0.187	0.011
Age	-7.792	-37.453, 21.870	0.608	0.001
Follow-up time	-0.035	-0.158, 0.089	0.585	0.002
gender	-17.520	-67.971, 32.931	0.498	0.003
Season: dark-dark**	75.040	-3.720, 153.799	0.065	0.021
dark-light**	135.706	60.682, 210.729	0.001	0.077
light-light**	96.042	14.051, 178.032	0.024	0.032

* Loss in explained fraction (R^2) by factor.
** Reference group (light – dark = 0)

The independent variables explained 90% of the variance in the second assessment of BMIsds, (Table 4). BMIsds (P<0.001) and age (P=0.03) were significantly associated with BMIsds at follow-up. The other independent variables, i.e. physical activity at baseline, physical activity at follow-up, gender, follow-up time and seasons, did not significantly contribute to the explained variation in BMIsds at follow-up.

Table 4. Multiple linear regression analysis between the dependent variable, BMI SDS at follow-up-and the independent variables: physical activity at baseline, physical activity at follow-up, BMI SDS at baseline, age, follow-up time, gender and seasons measured dark-dark, dark-light and light-light.
***b* = regression coefficient (slope); R^2 = amount of explanation.**

	R^2=0.90			
n=97	b	95% CI	p-value	ΔR^2 *
Physical activity at baseline	0.000	-0.001, 0.001	0.717	0.001
Physical activity at follow-up	-0.000	-0.001, 0.000	0.312	0.002
BMI SDS at baseline	0.908	0.841, 0.975	<0.001	0.812
Age	-0.144	-0.275, -0.013	0.034	0.006
Follow-up time	0.000	0.000, 0.001	0.528	0.001
gender	-0.057	-0.279, 0.166	0.618	0.001
Season: dark-dark**	-0.080	-0.429, 0.278	0.677	0.001
dark-light**	-0.065	-0.418, 0.288	0.718	0.001
light-light**	-0.071	-0.442, 0.301	0.711	0.001

* Loss in explained fraction (R^2) by factor.
** Reference group (light – dark = 0)

4.3 STUDY III

The prevalence of overweight and obesity in grade 2-4 was significantly reduced in the intervention group between baseline and follow up ($P<0.05$), as shown in Table 5. In contrast, an increase in the prevalence of overweight and obesity was observed in the control group. The corresponding 95% confidence interval for difference between intervention and control with respect to the proportion of children with a change including both overweight and obesity was 1.3% - 10.6%, ($P<0.05$) in favour of the intervention (Table 5). In gender-stratified analyses, only a minor increase in the proportion of children classified as overweight or obese was observed in control girls and no statistically significant difference was found compared to the intervention girls. For boys, the prevalence of overweight and obesity in the intervention schools was significantly reduced, whereas it increased in control schools. For children in grades 3-4 the difference in favour of the intervention was more pronounced: 9.2%, 95% confidence interval 3.3% - 16.9% ($P<0.01$). There was a statistically significant difference between boys in control and intervention schools ($P<0.05$), but no difference was found among girls.

Table 5 Prevalence of overweight and obesity respectively by calendar year (2001 and 2005) and gender

	Autumn 2001		**Spring 2005**						
	Intervention	**Control**	**Intervention**	**Control**	**Intervention**	**Control**	**Difference**	**95% CI**	
All	*n=719*	*n=671*	*n=591*	*n=430*	**2001-2005**	**2001-2005**	**Intervention-Control**	**Difference**	**P-value**
Overweight	16,7%	11,9%	13,9%	12,8%	-2,8%	0,9%	-3,7%		
Obesity	3,6%	4,2%	3,2%	6,1%	-0,4%	1,9%	-2,3%		
Overweight + obesity	20,3%	16,1%	17,1%	18,9%	-3,2%	2,8%	-6,0%	-10.6% ; -1.3%	<0.05
Girls	*n=355*	*n=329*	*n=304*	*n=200*					
Overweight	18,3%	12,2%	14,8%	12,5%	-3,5%	0,3%	-3,8%		
Obesity	3,1%	4,6%	3,3%	5,0%	0,2%	0,4%	-0,2%		
Overweight + obesity	21,4%	16,8%	18,1%	17,5%	-3,3%	0,7%	-4,0%	-10.6% ; 2.6%	
Boys	*n=364*	*n=342*	*n=287*	*n=230*					
Overweight	15,1%	11,7%	12,9%	13,0%	-2,2%	1,3%	-3,5%		
Obesity	4,1%	3,8%	3,1%	7,0%	-1,0%	3,2%	-4,2%		
Overweight + obesity	19,2%	15,5%	16,0%	20,0%	-3,2%	4,5%	-7,7%	-14.1% ; -1.2%	<0.05

Statistics presented are P-values and corresponding 95% confidence intervals for comparison between intervention and control schools.
Subjects in various calendar years are independent observations.

In analyses including the observed cases, a mean change from the first to the last observation in BMIsds was observed in favour of the intervention group (–0.01 BMISsds vs 0.3 BMIsds, effect size, with a 95% confidence interval 0.09 to 0.00; P=0.049). However, this difference was attenuated after adjustment for cluster of schools (P=0.14). The cluster correlation coefficient was low, <1%. Changes in BMIsds were correlated with age (P<0.001), with a more pronounced intervention effect in the older children. Sensitivity analyses using the FAS population revealed similar results as the analysis of the primary efficacy variable (data not shown). Analyses with a sub-group of children who had participated in the intervention for more than 2 school years showed no significant difference between intervention and control schools, with respect to mean change in BMIsds.

An increase in the proportions of children who shifted from overweight or obesity to normal weight were 14% and 7.5% respectively (P=0.017). In lean children in the intervention group (i.e., individuals with BMIsds <0) there were no signs of a negative effect on BMIsds, i.e. a decrease in BMIsds over time (P=0.31).

The overall levels of total physical activity tended to be higher for children in the intervention schools, compared to controls (P=0.06), however this association was attenuated after adjustment for cluster by school (P=0.10), Tables 6 and 7. Physical activity during after school care time was significantly higher for children in the intervention schools compared to controls (P=0.004), but this difference was also attenuated after cluster adjustment (P=0.27). No differences in physical activity was observed between intervention and control schools during school time and during evening time.

Table 6. Physical activity levels in children

	All				
Physical activity (counts per minute)	Intervention n=653 Mean (SD)	Control n=640 Mean (SD)	P-value	95% CI	P-value cluster*
School time weekdays, 8am-1.30pm	888 (199)	887 (202)	0.96	-21 - 23	0.92
After school care time weekdays, 1.30pm-4pm	953 (247)	913 (251)	0.004	13 - 67	0.27
Evening time weekdays, 4pm-9pm	676 (186)	665 (189)	0.31	-9 - 31	0.46
Total physical activity, 8am-9pm	789 (161)	771 (163)	0.055	0.3 - 36	0.10

* Cluster analysis where school and month were included as random factors in the ANCOVA model
Means, standard deviations (SD) and 95% confidence interval for physical activity (cpm).
P-values are based on ANCOVA and means are adjusted for calendar year, gender and age.

Table 7. Physical activity levels in girls and boys

	Girls					**Boys**				
	Intervention n=335	Control n=318	P-value	95% CI	P-value cluster*	Intervention n=318	Control n=322	P-value	95% CI	P-value cluster*
Physical activity (counts per minute)	Mean (SD)	Mean (SD)				Mean (SD)	Mean (SD)			
School time weekdays, 8am-1.30pm	838 (188)	830 (194)	0.62	-21 - 37	0.79	938 (210)	945 (210)	0.70	-40 - 26	0.94
After school care time weekdays, 1.30pm-4pm	887 (224)	868 (231)	0.30	-16 - 54	0.66	1020 (270)	958 (270)	0.004	20 - 104	0.15
Evening time weekdays, 4pm-9pm	665 (166)	659 (172)	0.63	-20 - 32	0.50	686 (204)	672 (204)	0.37	-18 - 46	0.53
Total physical activity, 8am-9pm	754 (152)	740 (157)	0.24	-10 - 38	0.29	823 (170)	803 (170)	0.13	-6 - 46	0.14

* Cluster analysis where school and month were included as random factors in the ANCOVA model

Means, standard deviations (SD) and 95% confidence interval for physical activity (cpm).

P-values are based on ANCOVA and means are adjusted for calendar year, gender and age.

Families with children from intervention schools in grades 3 and 4 reported healthier eating habits at home (i.e. decreases in high fat dairy products, sweetened cereals and sweet products) compared with those of children in control schools (Figure 7). Significant differences between children in intervention and control schools were found for high-fat dairy products (P=0.001), sweetened cereals (P=0.02) and sweet products (P =0.002). No differences were observed for consumption of bread (P=0.09), fast food (P=0.43), crisps/nuts (P=0.16), drinks (P=0.75), and fruit and vegetables (P=0.47). There were no differences between families from intervention and control schools regarding breakfast and dinner eating habits and the dinner and breakfast scores were similar (data not shown).

Eating habits varied partly with parental educational background. The proportion of families reporting an unhealthy consumption of fast food was greatest in families where the parents had a lower educational background, P<0.001.

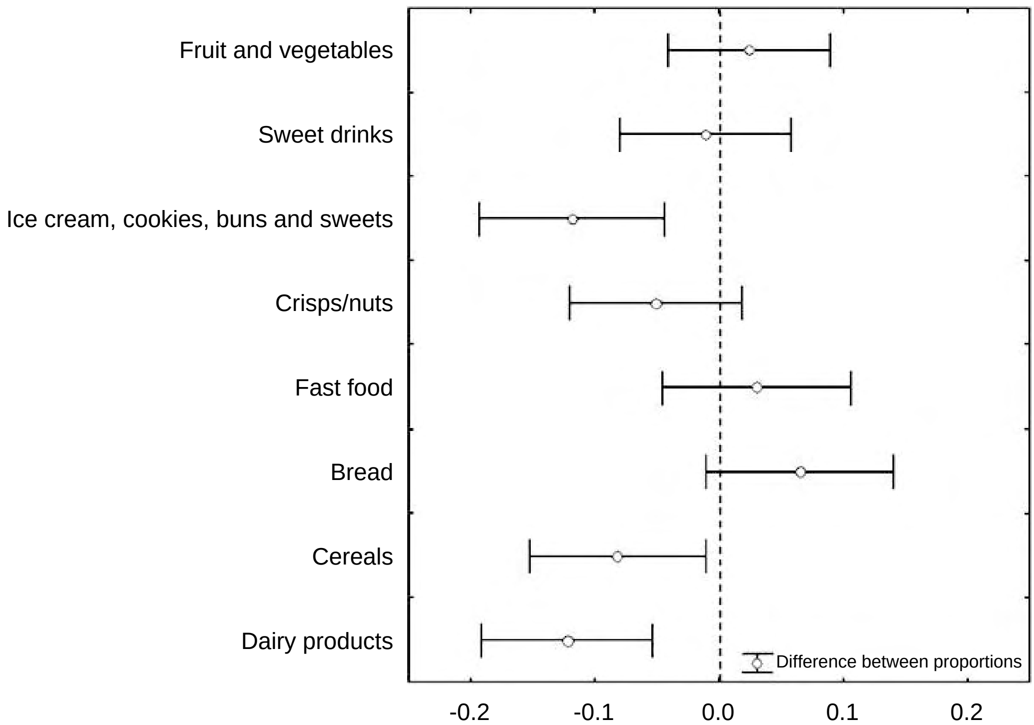


Figure 7. Difference in proportions between intervention and control families in unhealthy eating habits. Negative values denote lower prevalence of unhealthy eating habits in intervention.

Breakfast and dinner scores appeared to differ between the two parental education groups. The proportion of children with maximum breakfast score (=9) was 28% in families with lower parental background, whereas it was 43% in families with a higher parental educational background (P=0.01). Proportions of maximum dinner scores were 90%, compared to 94% in the two groups respectively (P=0.20).

A significant interaction effect between parental education and intervention was observed for reported intake of dairy products and fast food. For children in families

with low parental education background, the odds ratio (OR) was 3.58 with regard to healthy choice behaviour for dairy products in the intervention group compared with the control group, (OR=1.0), whereas for children in families with high parental education background the corresponding ORs for the intervention group and the control group were 1.65 and 1.18 respectively (P for interaction=0.02). The same patterns were observed with regard to the OR for healthy choice behaviour for fast food products, where ORs were 2.5 in the intervention group compared to 1.0 in the control group for children in families with low parental education background, whereas in families with high parental education background the corresponding ORs were 2.1 and 3.2 respectively (P for interaction=0.0005).
There was no difference between children from intervention and control schools with respect to eating attitudes, as assessed by the ChEAT questionnaire.

4.4 STUDY IV

The results show that none of the children had individual values above (triglycerides, systolic and diastolic blood pressure) or below (HDL) the cut-off values for the metabolic syndrome in children, according to International Diabetes Federation [91]. One child was categorised as having impaired fasting glucose (5.8 mmol/L) according to the American Diabetes Association criteria [117] (≥5.6 mmol/L).

Significant differences between weight groups were observed for metabolic risk score (P=0.03), fasting insulin (P=0.003), AUC insulin (P=0.01) and systolic blood pressure (P=0.02).

Cardio-respiratory fitness was negatively associated with fasting insulin (β= -0.410, P=0.003, 95% CI = -0.674, -0.149). Also, a significant negative association between physical activity and insulin (AUC) (β= -0.258, P=0.04, 95% CI = -0.500, -0.016) was observed. The relationship remained statistically significant after additional adjustment for cardio-respiratory fitness (β= -0.253, P=0.048, 95% CI = -0.503, -0.002). No other statistical associations were observed between physical activity and clustered metabolic risk and single metabolic risk factors.

The first measurement (baseline) and the mean of the first and last (follow-up) measurement of physical activity were analysed and correlated to AUC insulin. AUC insulin showed no association with the first physical activity measurement (β= -0.126, P=0.33, 95% CI = -0.382, 0.130) and no association with the mean value of the first and last physical activity measurements (β= -0.202, P=0.11, 95% CI = -0.452, 0.047). The mean total physical activity decreased by approximately 7% between baseline and follow-up measurements of physical activity (730 cpm vs. 677 cpm).

5 DISCUSSION

5.1 PHYSICAL ACTIVITY

5.1.1 Age differences in physical activity

The results from this thesis suggest that the decline in physical activity in children may start already at the age of 6 years. In addition, results show that there are no differences between ages in the decline of physical activity levels between weekdays and weekends.

The longitudinal data from Study II and Study IV show a decline with increasing age in physical activity over time by 6% and 7 % and that was similar to what has been previously observed [37]. The decline in physical activity can not fully be explained by seasonal effect, as 51 of the children were re-tested during the same season and more children had repeated measurements in the light period (n=30) compared to the dark period (n=16) (Study II). It is possible that biology explains some of the decline in physical activity over time but there is also the possibility of modern society influencing children to a more physically inactive lifestyle already in this young age group.

Previous studies have suggested a decline in physical activity by age between 9 and 18 years [16,18,19,22-25,28] and across age groups, consistently suggesting lower activity in older age groups [20,118-120]. Recent data using accelerometry from the NHANES study suggest that activity levels are lower in adolescents compared with young children [121]. A recent longitudinal study (n=1032) reported that moderate and vigorous physical activity (MVPA) declined between ages 9 and 15 and this decline was similar for girls and boys [122].The steepest decline in physical activity has previously been suggested to occur during adolescence, that is between the ages of 13 and 18 years [27], and a recent review suggested that physical activity levels increases between the ages of 3 and 8 years [21]. Our results extend these previous observations, suggesting a decline in objectively measured overall physical activity levels across age groups between ages 6 and 9 years. Part of the decline in overall physical activity levels might be explained by more scheduled time spent at school with increased age. However, this is probably not the most important factor, as our results also suggested a decline in physical activity by age during weekends. This may at least partly suggest a biological explanation for the decline by age in spontaneous physical activity, as observed in other species [27]. However, it is also possible that an increased use of computer games, TV and other sedentary behaviours contribute to this decline.

5.1.2 Gender differences in physical activity

Boys are consistently more physically active than girls across age groups i.e. between 6 and 9 years of age. Overall, boys were 8% more active than the girls. Differences in physical activity levels between gender in total physical activity were also shown in Study II and Study IV. The difference in physical activity levels between gender was decreased between repeated measurements of physical activity in both Study II and Study IV. Further, there was no difference observed between boys and girls in the

decline of physical activity across ages (6-9 years). However, a difference was found in the weekly pattern of physical activity where both boys and girls decreased their physical activity between weekdays and weekends but the decrease was higher in boys. Moreover, the physical activity gap between girls and boys varied at different time periods. The difference was highest during school time and after school care time. The stability of physical activity showed a stronger correlation between physical activity at baseline and physical activity at follow-up for boys compared to girls.
Our results corroborate previous observations consistently demonstrating that boys are more physically active than girls [15-20] but to our knowledge only one previous study (n=698) using accelerometers to measure physical activity has demonstrated a gender difference among 6 to 7-year-old children (9). The gender difference in mean physical activity in the Danish study was comparable with the present results. Gender differences were explained by significantly higher activity levels in boys during school and after school care time. In contrast, there was no significant difference in physical activity between girls and boys in the weekday evenings. It is unclear whether the gender differences are due to the fact that the school environment and physical education classes are more adapted towards boys or if the difference mirrors biological or social variations in social interaction among boys and girls. Boys, but not girls are physically active if play areas in schools are improved, suggesting differences in play styles between girls and boys [123]**.** The gender differences in physical activity might be important information when planning interventions to increase girls' physical activity.

5.1.3 Stability/tracking of physical activity

The results of Study II suggest that physical activity levels are relatively stable over a period of approximately 1.5 years in 6-10 year old children. In study IV the results are similar in the sub-group of children with two measurements of physical activity. The results of Study II and Study IV are in accordance with three previous studies [37-39]. One of these studies also measured physical activity by accelerometry [37]. They observed correlation coefficients between 0.32 and 0.38 in 379 children aged 5.6 years at baseline, with a follow-up time of 3 years. Compared to our studies (r=0.59/r=0.68) the degree of tracking was lower and may be explained by a difference in age and a shorter follow-up time in our studies. Interestingly, Janz and colleagues also showed that a sedentary behaviour showed better stability than overall physical activity.
Longitudinal studies from Sweden and Finland [124,125] suggest that early experiences of physical activity during childhood and adolescence play an important role in the maintenance of an active lifestyle during early adulthood. Furthermore, a recent longitudinal study demonstrated that a high level of physical activity between ages 9 to 18 significantly predicts high levels of physical activity in adulthood [36].

5.1.4 Variation in physical activity

Mean daily physical activity was lower during weekends compared to weekdays showing a decrease of 17% in boys and 15% in girls. Previous studies have reported higher levels of physical activity during weekdays compared with weekend days in 8 to 11-year-old children from various countries [16,17,55]. In a French study with primary school children (mean age 9 years, n=64), mean physical activity levels were lower during school free days compared to school days [29]. Similarly, moderate and vigorous physical activity (MVPA) was higher in adolescent girls (n=1603) on weekdays compared to weekends [126]. On the contrary, in another study a sub-group of children in grade 1-3 (n=92) showed higher levels of MVPA during the weekends compared to weekdays [30]. Finally, compared with this present study, data from the ALSPAC study (n=5595) suggested a similar activity pattern between weekdays and weekend days in 11-year-old boys and girls [55]. Our results suggest that this pattern is evident already in 6 and 7-year-old children.

It was recently concluded that the amount of physical activity accumulated during school time appeared not to be enough to achieve the current recommendations for health enhancing physical activity in children [127]. We found an activity pattern with low activity levels during leisure time in children as young as 6-7 years and it is therefore possible that this is a relevant concern for young children also. It is likely that most children in this age group spend the vast majority of their leisure time with their family. Therefore, family involved interventions may be a prerequisite to increase physical activity in this age group, although, the results of family interventions are so far discouraging [128].

Physical activity levels during school time vs. leisure time were recently examined in 9 and 15-year-old children, suggesting that socio-cultural factors may influence on the amount of activity [34]. A small study (n=58) including 7 to 11-year-old children from England showed that physical activity behaviours were more consistent in school compared to the time period after school [31], whereas 8 to 15-year-old Portuguese girls were more physically active during school periods while boys were more active after school [33]. Further, a small study (n=54) studied activity patterns within days between active and less active 10 to 15-year-old girls [32]. They observed that the active girls were significantly more engaged in MVPA outside of school than the less active girls.

5.1.5 Physically active versus physically inactive children

Study I shows that the magnitude of decline between weekdays and weekend days were similar across activity groups suggesting this decline in activity is consistent regardless of overall activity levels. The results are in accordance with Riddoch et al. suggesting that the daily activity pattern was similar between the most and the least physically active children (highest and lowest quintiles) [55]. This is a surprising finding for us. Our hypothesis was that active children would be even more active during school-free days. Obviously sedentary activities are attractive for all children. It is possible that the pattern would have been different if the intensity of physical activity had been measured and not only the mean total physical activity.

The results of Study II suggest a slightly stronger relationship between baseline and follow-up measurements of physical activity for children in the most active group (r=0.74) compared to the least active group of children (r=0.55). A possible explanation is that the week-to-week differences are less pronounced if you are physically active with scheduled sports activities several days per week.

5.2 INTERVENTION

5.2.1 The role of physical activity in obesity prevention

The school-based obesity intervention showed that physical activity levels did not differ between intervention and control schools after cluster adjustment. Study III examined the differences in physical activity levels between intervention and control schools in total physical activity, during school time and after school care time. Overall physical activity tended to be higher in intervention schools compared with control schools. However, this difference was attenuated after further adjustment for cluster by school, indicating variation by school. Physical activity during school time did not differ between intervention and control schools even though all teachers in the intervention schools reported that they implemented thirty minutes of additional physical activity per day during school time. It is possible that schoolteachers did not report this part of the intervention correctly and this was also difficult to supervise for the STOPP research staff. However, it is also possible that children in intervention schools compensated for this by being less physically active during other parts of the school day, or a combination of both. The interest in implementing the programme varied considerably among the teachers and some teachers reported that it was difficult to integrate physical activity into their ordinary lessons. Reducing sedentary time during after school care time appeared to be partly successful. A statistically significant higher physical activity level was observed in intervention schools at this time of the day, although this difference did not persist after cluster adjustment.

5.2.2 Overweight and obesity

The prevalence of overweight and obesity decreased in intervention schools compared to control schools. There was no difference between intervention and controls, after cluster adjustment, in the longitudinal analysis of BMIsds changes. However, a larger proportion of the children in the intervention group who were initially overweight reached normal weight compared to children in the control group.

After four years of intervention, the prevalence of overweight and obesity in grades two, three and four children in the intervention schools was significantly reduced, while, conversely, there was an increase in control schools. In analyses including all children who participated in the study for at least one school year, the difference between intervention and controls in the change in BMIsds did not show statistical significance after adjustment for cluster by school. However, the proportion of children who were initially overweight or obese and who reached normal weight was larger in the intervention schools.

Although results are difficult to compare due to variations in methodology, duration and social setting, the results in the present study were better than expected from previous studies [104,100,102,129]. One possible factor of importance might be our focus on creating a school and after school care environment with restricted access to sweetened products and beverages.

The programme was designed to be an integrated, sustainable part of the ordinary school curriculum, possible to maintain within the ordinary school budget. Random documented school visits by the study staff indicate that the implementation of the intervention including healthy school lunches and afternoon snacks was, with minor divergences, successful in all intervention schools. Removal of all types of sweets was more difficult to accept for the school staff and required frequent reminders from the STOPP staff. The control schools were instructed not to change their health promoting policies during the study period. However, due to the public interest in the childhood obesity epidemic some of the control schools performed changes in their school lunches and afternoon snacks during the intervention period. While the STOPP-project was still ongoing the Swedish government increased the focus on healthy dietary eating habits and physical activity in schools. In 2001 the National Food Administration launched guidelines for schools regarding healthy school lunches and afternoon snacks. Furthermore, an amendment in the school curriculum was included recommending all schools to offer all children daily physical activity during the school day (in addition to physical education classes). These changes were out of control for the researchers, but are unavoidable in any type of public intervention and they may have affected the results, reducing differences between intervention and control schools. This is also in agreement with a Swedish study [64] showing that between 2000 and 2005 the obesity epidemic may have eased off in 10 to 11-year-old children and possibly reversed among girls. Therefore, the societal changes might have influenced the children in the control schools and that could be one reason for us not detecting any significant differences in physical activity levels and BMIsds levels between control and intervention schools. The effect of the intervention with regard to the prevalence of overweight and obesity between 2001 and 2005, was more pronounced in boys than in girls, which is in contrast to what has been observed in more education-based obesity prevention programmes [104]. Recent Swedish epidemiological data have indicated a reduced prevalence of overweight and obesity among girls but not among boys [63] and it is possible that this secular trend has attenuated the study effect among girls. However, in the present study there was a stronger trend, although not statistically significant, for longitudinal BMIsds changes in girls compared to boys.

5.2.3 Eating habits

Eating habits at home were found to be healthier in families with children in intervention schools at the end of intervention.

Although the intervention was focused on eating habits at school and not on health education per se, we observed, in three out of eight food domains, a more healthy food intake in the families from intervention schools at the end of the intervention. It is likely that this is an effect of the intervention, as other aspects such as breakfast and dinner habits not dealt with in the intervention programme did not differ. These results might suggest that changes in school lunches and after school care snacks, in combination with strict rules and attitudes against unhealthy eating among professional caretakers, facilitate parental selection of more healthy food alternatives.

We found a social gradient, with a less healthy eating pattern among families with less educated parents. This is in agreement with a higher prevalence of obesity in children from families with lower parental education [63]. Interestingly, the difference between intervention and control families was more pronounced among families with a low parental education, indicating that the STOPP programme might predominantly influence the behaviour in high risk families.

5.2.4 Eating attitudes

Importantly, there was no difference between children in intervention and control schools with regard to self-reported eating attitudes.
With rising prevalence of overweight and obesity in the population there is also an elevated risk for body dissatisfaction [130]. Previous studies have shown that young children are influenced by ideals promoting extreme thinness, particularly in women, and that weight concerns start at an early age [131,132]. As recently suggested [133], obesity interventions should take these issues into account, including an evaluation determining whether these programmes increase the risk of unhealthy food-restraint and, subsequently, eating disorders. We found no signs of negative effects of the intervention, as measured by self-report. There was no effect of the intervention on BMI in lean children (BMIsds >0) and the ChEAT results were almost identical in intervention and control schools. Thus, the type of intervention here presented seems not to be harmful.

5.3 METABOLIC RISK FACTORS, PHYSICAL ACTIVITY AND OBESITY

The results suggest that there is a significant difference between normal weight and overweight children in clustered metabolic risk, insulin levels (AUC and fasting) and systolic blood pressure. The differences in metabolic risk factors between weight groups could not be explained by physical activity or fitness although physical activity and cardio-respiratory fitness were associated with lower insulin levels in the entire group.
Low physical activity and low cardio-respiratory fitness are associated with an increased risk of the metabolic syndrome in adults [93] but there is less evidence concerning the associations of physical activity, cardio-respiratory fitness and metabolic risk factors in children. Study IV shows that there was a significant association between physical activity and insulin, AUC, as well as between cardio-respiratory fitness and fasting insulin, thus confirming the associations between physical activity, cardio-respiratory fitness and insulin sensitivity among pre-pubertal children. A study (n=897) with normal and overweight children (mean (SD) age 10.8 (3.8) years), found an inverse relationship between physical activity and fat mass, $VO_{2\ peak}$, fasting insulin and waist circumference [118].
Ekelund and co-authors [48] observed an inverse relationship between total physical activity independent of aerobic fitness in 9-year-old children. These associations between physical activity and metabolic risk scores are also reported to be independent of adiposity [48,94,95]. Conversely, a study (n=529) with Swedish 9-year-olds did not find any associations between physical activity and clustered metabolic risk [19]. There is possibly a difference in the range of physical activity levels between children from different countries. It could be that Swedish children are a more homogenous group compared to English children in physical activity levels and therefore associations between physical activity and metabolic risk factors are more difficult to observe.
Interestingly, there were no associations between the earlier measurements of physical activity and present insulin release, despite the fact that a relatively good correlation was found between the physical activity measurements. The correlation between the two measurements confirms previous results for 6 to 10-year-old children from the

STOPP-project [110]. This might indicate that a measurement of physical activity during a week performed within 5-6 months before the insulin measurements are associated with insulin release, whereas physical activity measurements performed one or two years before are not. This might suggest that the health effects of physical activity can not be preserved or maintained for a longer time.

Also, an issue to take into consideration is that physical activity is a behaviour that varies on a daily basis within individuals compared to adiposity, which is a relatively static condition, which takes time to change. This is also demonstrated in Study II by the higher stability between baseline and follow-up measurements with BMIsds compared to physical activity. Therefore, this might influence the ability to measure the associations between physical activity and clustered metabolic risk and it is important to have in mind that there might be an underestimation of the true associations between physical activity and metabolic risk.

Cardio-respiratory fitness has, in a few studies, been found to be inversely related to clustered metabolic risk and metabolic risk factors in children [48,85-87].

In this study the results suggest that adiposity mainly explained the differences between weight groups in clustered metabolic risk. There was a difference in metabolic risk between weight groups, even though only 5 children were classified as obese and 24 as overweight. Still, an increased metabolic risk could be found already in a group of children that were mainly overweight and not obese.

A recent study, reported that both overweight and obesity in late adolescence increased the risk of adult mortality in men followed for 38 years [134]. However, there is limited data on the difference in metabolic risk factors between moderately overweight and normal weight pre-pubertal children. Earlier studies have observed differences in cardiovascular and metabolic risk factors between normal and obese children but have not included overweight children [135,136] . Furthermore, many studies include children within a wide age range, often combining pre-pubertal children with adolescents [137-140]. Davis and colleagues (n=211) [138] reported that normal weight children were less likely to have metabolic syndrome than obese and overweight children aged 7 to 18 years. Moreover, a recent French study (n=452) [137] showed that modest overweight in 8 to 17-year-old children was related to increased levels of cardiovascular risk factors. Of the overweight children 7.7% had at least 2 risk factors among high blood pressure, TG, glucose and low levels of HDL, compared to 0.25% of the children with normal weight. The Bogalusa Heart Study [71] found that the prevalence of cardiovascular risk factors increased with higher levels in BMI index percentiles in the combined group of 5 to 10-year-old children. A recent study [139] including 9, 13 and 16- year-olds (n=3613) categorised children into normal weight, overweight and obese groups from BMI percentiles. They observed that both overweight and obese children showed a significantly higher prevalence of cardio-metabolic risk factors compared to normal weight children. However, the age groups were analysed together and age group specific results were not reported, thus limiting its comparability with the present study. Similarly, a large cohort (n=13, 086) observed that both overweight (75.4%) and obese (81.9%) 7 to 12-year-old Iranian children had at least one cardiovascular risk factor [141]. In addition, in a Brazilian study [140], the metabolic syndrome was 0.3% in normal weight vs. 10.7% in overweight school children aged 6 to 16 years. Moreover, a study with 215 Chinese children [142] aged 7.5 to 13 years demonstrated, according to Chinese BMI criterion, that overweight children showed significantly higher triglycerides compared to normal weight children.

In corroboration with previous studies, we have observed that there is a difference in higher metabolic risk between overweight children compared to normal weight children. We have extended previous findings by showing that there is a higher metabolic risk between normal weight and moderately overweight pre-pubertal children in a homogenous age group. Furthermore, this study compared, to previous studies, has included objective measurements of physical activity and cardio-respiratory fitness in order to explain differences between weight groups. Of note, the American Academy of Pediatrics and the American Heart Associations are currently suggesting that there should now be increased focus on overweight children [143].

Several previous studies have shown that metabolic risk factors track over time from childhood to adulthood, leading to an increased risk of developing diseases later in life [96,98,144-147]. Importantly, the Cardiovascular Risk in Young Finns Study [97] recently reported that youth determinants for the development of the metabolic syndrome in adulthood were obesity, high triglycerides, family history of hypertension and age observed in children aged 3 to 9 years at baseline.

5.4 DETERMINANTS OF PHYSICAL ACTIVITY

Physical activity is difficult to measure, as it is a behaviour influenced by many factors such e.g. as the transition process from staying at home to attending preschool and school, as well as by social, psychological and environmental determinants [148]. On the other hand it has recently been suggested that physical activity is centrally regulated and independent of the environment [149]. These authors suggested that children with more timetabled physical education and children who commuted to school by active transport did not differ in total weekly physical activity compared to children unexposed to this extra physical activity. In contrast, a recent twin study suggested that physical activity was explained by the shared environment [150].

5.5 FACTORS OF IMPORTANCE IN THE ASSESSMENT OF PHYSICAL ACTIVITY

It can be debated whether physical activity levels are higher on the first day of assessment due to a “reactive effect”. A recent study of 11-year old British children [55] showed that physical activity was higher on the first day of measurement compared with the remaining days. In contrast, physical activity levels were higher on the last measurement day compared with the first day in our study. Furthermore, no difference in mean physical activity was observed between children as an effect of the number of days (4-7 days) of valid data. This then suggests that our results are not influenced by a “reactive effect”.
Earlier studies have demonstrated conflicting results in mean physical activity depending on the number of days of measurement. One study showed that activity levels were higher in children with three days of measurement compared to four days [14], whereas others have suggested lower mean activity levels from a three day registration compared to four days [18].The children in our study had their monitors on for more than six days, which has previously been shown to indicate a high day-to-day

reliability in the measurement of physical activity with accelerometers [30]. A shorter assessment period might result in higher physical activity levels compared to children's normal activity levels due to children being aware of wearing the monitors.

The results of Study II indicate that baseline physical activity and seasons were significantly associated with levels of physical activity at follow-up. Gender, age, BMIsds and follow-up time did not significantly contribute to the explained variation in physical activity at follow-up. Consequently it is important to consider the seasonal variation when physical activity is evaluated in this age group. Our results confirm a seasonal influence on physical activity levels, with children being more physically active during summer compared to winter, which confirms previous findings [151-153].

5.6 STRENGTHS AND LIMITATIONS

5.6.1 Strengths

The STOPP-study included a large randomised cohort of children and the intervention was going on for a long time period. Further, the age group of 6 to 10-year-olds has previously not been widely studied in school-based obesity interventions.
An objective measurement has been used for assessing physical activity. In addition, we have measured physical activity for seven consecutive days and have repetitive measurements of physical activity.
Further, we have studied differences in metabolic risk between moderately overweight children and normal weight children, in a homogenous age group of pre-pubertal children.

5.6.2 Limitations

When interpreting our results the following limitations should be considered.
The children in the study were exposed to the intervention during a time period ranging between 1-4 years and therefore only 311 children participated for the full duration of the intervention. Almost one third of the children participated for only one year and that time period might have been insufficient to detect a change in BMIsds. Furthermore, we did not have any control of physical activity and dietary behaviours during the summer holidays and this might negatively affect the long-term effects of the intervention. The summer periods have been shown to be associated with an increase of body fat in children who have improved their body composition during a school-based intervention. [154]
The family food questionnaire has not been validated, which could have implications on the results and the questionnaire was only answered at the end of the study. Physical activity and ChEAT were measured continuously during the study period. Thus, we have no comparable data obtained before the intervention. However, environmental characteristics were very similar for intervention and control schools and there were no differences in socioeconomic or educational status of the parents. Therefore it is unlikely that the observed differences were present before the initiation of the intervention.

Participating children are part of an obesity intervention. However, it is unlikely this will bias the results as the intervention did not produce a significant difference in overall mean physical activity between intervention and control schools.
In study IV the sample sizes in the weight groups were relatively small. It may be possible that power was insufficient and that physical activity and cardio-respiratory fitness might explain the differences in metabolic risk between weight groups in a larger sample of children. However, we could not detect any clinical indications or trends indicating that a larger sample size would have resulted in physical activity explaining differences between weight groups.
As previously mentioned, there are limitations with accelerometry when measuring movement in the horizontal plane and during swimming when the monitors can not be worn. Finally, we have not examined the length of time spent at different intensity levels, which may be of importance when studying variations over time, associations with metabolic risk factors and role in obesity prevention.

5.7 FURTHER RESEARCH

Future intervention studies examining whether changes in physical activity in early life will have long standing effects on physical activity and health are urgently needed.
The results of the intervention suggest that the physical activity probably only contributed to a minor extent to the observed change in overweight prevalence between intervention and control schools. Thus, it remains to be established whether successful physical activity intervention can further improve the outcome of this type of intervention.
Importantly, the environmental and genetic relationships with physical activity, fitness and metabolic risk factors need to be established through intervention studies.

6 CONCLUSIONS

This thesis has shown:

- A decline in objectively measured physical activity across ages between ages 6 to 10.

- Consistently lower physical activity levels during weekends and evening time compared with school times. These activity patterns were similar across low, medium and highly active children.

- Girls were consistently less active than boys, but the differences were most pronounced during school and after school care time.

- Repeated measures show that physical activity levels are fairly stable in children and high levels of physical activity were more stable than low levels of physical activity.

- A school-based intervention including healthy school lunches and after school care snacks, in combination with strict rules against unhealthy eating can reduce the prevalence of overweight and positively influence eating habits at home. It is unlikely that the physical activity levels contributed substantially to the result, as no difference in physical activity levels between intervention and control schools was observed, despite the school level intervention.

- Young overweight pre-pubertal children show significant higher metabolic risk compared to normal weight children. The differences in metabolic risk factors between weight groups could not be explained by physical activity or fitness. Physical activity and cardio-respiratory fitness were associated with insulin levels. This suggests a detrimental effect of moderate excess of adiposity already at an early age and highlights the importance of preventing overweight in children from an early age, in order to prevent the emergence of the metabolic syndrome and its associated diseases. Intervention studies are needed to show whether increases in physical activity levels will have beneficial effects on metabolic risk factors.

We are all aware, irrespective of being a researcher in this area, that childhood obesity is a major health problem and due to the complexity of the disease, it is very difficult to prevent (and even worse to treat). Therefore, we all need to make a contribution for the sake of our children and their current and future health.

"Do not always follow the common path.
Take a different path and leave footprints."

Unknown

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