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262

Marja Leppänen

Physical Activity During Pregnancy and Early Childhood from the Perspective of Gestational Diabetes Risk and Children's Body Composition

JYVÄSKYLÄN YLIOPISTO

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ABSTRACT

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This study investigated the factors associated with self-reported leisure-time physical activity excluding household activities (LTPAexHH) among women at risk for gestational diabetes (GDM), change in self-reported LTPA including household activities (LTPAinHH) from pre-pregnancy to 7-year follow-up as well as the influence of risk for GDM on their children's physical activity (PA) and body composition. The association between maternal and child PA, and associations of PA with body composition and physical fitness in preschoolers were also studied.

A sample of 399 pregnant women at risk for GDM was examined in a cohort study, and 199 mother-child dyads were assessed in cross-sectional and longitudinal analyses based on a Finnish NELLI study. Additionally, samples of preschoolers were assessed in cross-sectional (n=307) and longitudinal analyses (n=138) based on a Swedish MINISTOP study. PA was evaluated using subjective (questionnaire) and objective (accelerometer) methods. Factors associated with LTPAexHH were collected with questionnaires and maternity cards. Body composition and physical fitness were assessed. The results showed that among women at risk for GDM self-reported pre-pregnancy LTPAexHH and social support were positively associated with self-reported LTPAexHH during pregnancy, whereas health-related issues and lack of time restricted it the most. The women at risk for GDM engaged less than peers in self-reported LTPAinHH over 7-year follow-up. Additionally, maternal objectively measured PA was associated with children's PA at 7-year follow-up. Moreover, high-intensity PA was related to healthier body composition and better physical fitness in preschoolers.

In conclusion, women's PA before, during and after pregnancy seem to improve PA and body composition in two generations. Additionally, high-intensity PA at young ages may support long-term health benefits for childhood body composition and physical fitness.

Keywords: Physical activity, pregnancy, gestational diabetes risk, body composition, physical fitness, children

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Helsinki, July 2017
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LIST OF ORIGINAL PUBLICATIONS

The dissertation is based on the following original publications, which are referred to in the text by their Roman numerals.

I Leppänen, M. H., Aittasalo, M., Raitanen, J., Kinnunen, T. I., Kujala, U. M. & Luoto, R. Physical activity during pregnancy: predictors of change, perceived support and barriers among women at increased risk of gestational diabetes. Maternal and Child Health Journal 2014; 18: 9. doi: 10.1007/s10995-014-1464-5.

II Leppänen, M. H., Raitanen, J., Husu, P., Kujala, U. M., Tuominen, P. & Luoto, R. Physical activity in children and their mothers stratified by gestational diabetes risk: a 7-year follow-up. 2017. Submitted.

III Leppänen, M. H., Nyström, C. D., Henriksson, P., Pomeroy, J., Ruiz, J. R., Ortega, F. B., Cadenas-Sánchez, C. & Löf, M. Physical activity intensity, sedentary behavior, body composition and physical fitness in 4-year-old children: results from the Ministop trial. International Journal of Obesity 2016; 40: 7. doi: 10.1038/ijo.2016.54.

IV Leppänen, M. H., Henriksson, P., Nyström, C. D., Henriksson, H., Ortega, F. B., Pomeroy, J., Ruiz, J. R., Cadenas-Sánchez, C. & Löf M. Longitudinal physical activity, body composition and physical fitness in preschoolers. Medicine & Science in Sports & Exercise 2017; 49: 10. doi: 10.1249/MSS.0000000000001313.

ABBREVIATIONS

ADP	air displacement plethysmography
BF%	body fat percent
BIA	bioelectrical impedance analysis
BMI	body mass index
CI	confidence interval
cm	centimeter
coeff.	coefficient
FFMI	fat-free mass index
FMI	fat mass index
GDM	gestational diabetes mellitus
gw	gestational weeks
INT	intervention group
kg	kilogram
LPA	light-intensity physical activity
LTPAexHH	leisure-time physical activity excluding household activities
LTPAinHH	leisure-time physical activity including household activities
m	meter
MAD	mean amplitude deviation
MET	metabolic equivalent
min	minute
MPA	moderate-intensity physical activity
MVPA	moderate-to-vigorous-intensity physical activity
OR	odds ratio
PA	physical activity
s	second
SB	sedentary behavior
SD	standard deviation
UC	usual care group
WHO	World Health Organization
VM	vector magnitude
VPA	vigorous-intensity physical activity

CONTENTS

1 INTRODUCTION

Sedentary behaviour (SB), overweight and obesity are current major health concerns in both children and adults. Physical activity (PA), owing to its multiple health benefits, including a positive influence on energy balance, has been considered one of the key factors in countering these problems. Lifestyle is likely to transfer from one generation to another, and hence there is growing research interest in how knowledge about a healthy lifestyle can be directly transferred to the next generation. Thus, owing to increased motivation and frequent access to medical supervision, pregnancy has been found to be an ideal time for adopting a healthy lifestyle (Ferrara et al. 2011), and it might also be a potential time to influence the health of two generations simultaneously.

Regular PA is highly recommended at all stages of life due to its positive influence on health, such as reducing the risk of obesity and associated comorbidities as well as maintaining and improving cardiorespiratory fitness (Physical Activity Guidelines Advisory Committee 2008). Additionally, PA during pregnancy can reduce excessive gestational weight gain (Muktabhant et al. 2015, Forczek, Curyło & Forczek 2017), enhance psychological well-being (Forczek, Curyło & Forczek 2017) as well as may reduce the risk for the development of gestational diabetes (GDM) (American College of Obstetricians and Gynecologists (ACOG) 2015). Despite the many health benefits, studies suggest that PA recommendations are rarely met in the general population (Hallal et al. 2012, Helldán & Helakorpi 2015), in children (Kovacs et al. 2014) or among pregnant women (Juhl et al. 2012, Gjestland et al. 2013, Santos et al. 2014, Hesketh & Evenson 2016). It is thus evident that substantial health benefits are lost due to insufficient PA at different stages of life, and that better knowledge of the factors related to increased engagement in PA would help professionals in health care to more effectively promote health-enhancing PA.

Insufficient PA among children has raised concern, especially given the high prevalence of overweight/obesity. Childhood obesity is a growing public health problem worldwide (World Health Organization (WHO) 2017b) and has been associated with many physical and psychological consequences, such as metabolic risk factors and decreased health-related quality of life (Pulragon 2013).

Overweight/obesity has been found to progress from early childhood to adolescence (Nader et al. 2006, Reilly et al. 2011) requiring interventions early in life to support a healthy lifestyle, and thus prevent the development of obesity.

Physical fitness has been considered an important marker of health in children and adolescents (Ortega et al. 2008, Ruiz et al. 2009). Improvements in cardiorespiratory fitness have been related to a reduced risk of being overweight/obese in puberty (Ortega et al. 2011) and to improved cardiorespiratory health in adulthood (Cliff, Reilly & Okely 2009). Additionally, muscular strength has been positively associated with psychological health (Padilla-Moledo et al. 2012) and decreased all-cause premature mortality (Ortega et al. 2012), while improvements in muscular strength from childhood to adolescence have been negatively associated with changes in overall adiposity (Ruiz et al. 2009). Previous studies on physical fitness have focused on adults and older children, while only a few studies have examined the associations between PA and physical fitness in younger children (Bayer et al. 2009, Bürgi et al. 2011, Timmons et al. 2012).

GDM is a complication of pregnancy associated with increased risk for adverse health outcomes for both mother (Rich-Edwards 2009) and offspring (Garcia-Vargas et al. 2012) during pregnancy and in later life. The prevalence of GDM is increasing globally (Bardenheier et al. 2015): in Finland, for example, 12.6% of women were diagnosed with GDM in 2016, while the number was 7% in 2010 (Vuori & Gissler 2016). Well-recognized risk factors for GDM are advanced maternal age, overweight, family history of type 2 diabetes as well as GDM or glucose intolerance in previous pregnancies (Petry 2010, Zhang, Rawal & Chong 2016). In Finland, the body mass index (BMI) of pregnant women was with a mean of 24.7 kg/m^2 in 2016 (Vuori & Gissler 2016), and the prevalence of obese women (BMI >30 kg/m^2) has increased from 11.8% to 13.3% between 2010-2016 (Vuori & Gissler 2016). In addition, the mean age of all women giving a birth was 30.6 years, and 20.8% of them were 35 years or over (Vuori & Gissler 2016). Previous studies have focused on investigating the influence of diagnosed GDM on health outcomes, with follow-up periods ranging from few months to up to one year. There is, therefore, an urgent need to clarify how being at risk for GDM influences the health of mothers and their offspring in the long term.

This research aimed to investigate the factors associated with leisure-time PA excluding household activities (LTPAexHH) during pregnancy among women at risk for GDM. The influence of GDM risk on both the women's leisure-time PA including household activities (LTPAinHH) and/or objectively measured PA in the long term and their children's PA and body composition in early childhood (aged <7 years) were additionally examined. Furthermore, the association of maternal pre-pregnancy LTPAinHH and objectively measured PA at 7-year after the delivery with children's PA in early childhood as well as the associations of PA and SB with body composition and physical fitness in preschool children (aged 3-5 years) were investigated in cross-sectional and longitudinal designs.

2 REVIEW OF THE LITERATURE

2.1 Physical activity and sedentary behaviour

PA is defined as "any bodily movement produced by skeletal muscles that results in energy expenditure" (Caspersen, Powell & Christenson 1985). To develop and function in an optimum way, the human body requires stimulation by frequent PA (Booth et al. 2008). SB has been described as "any waking behaviour characterized by an energy expenditure ≤1.5 metabolic equivalents (METs) while in a sitting or reclining posture", where one MET means the rate of energy expenditure while sitting at rest (Sedentary Behaviour Research Network 2012).

There are many factors that have been reported to influence on PA and SB in children and adults (Bauman et al. 2012, Choi et al. 2017). In order to plan and produce effective public health interventions, further knowledge on the correlates (factors associated with PA) of PA in different stages of life is required. One of the commonly used model in health promotion is an ecological model (McLeroy et al. 1988). In the model, behaviour is viewed from five levels: 1) *intrapersonal factors* (individual-related characteristics, such as knowledge, attitudes, self-concept and skills), 2) *interpersonal processes and primary groups* (such as social support system including the family, friends and work group), 3) *institutional factors* (social institutions with organizational characteristics, rules and regulations for operation), 4) *community factors* (relationships among organizations and institutions), and 5) *public policy* (local, state, laws and policies) (McLeroy et al. 1988). The model assumes that changes in the social environment will produce changes in individuals, and furthermore, the support of individuals in the population is needed for implementing environmental changes. Yet, in order to promote interventions effectively, it is essential to pay attention to multiple levels at the same time (e.g. individual, work group/family, and social institutions).

In the following sections, PA, SB and health (2.1.1) will be viewed first during adulthood (2.1.1.1), secondly during pregnancy (2.1.1.2), and thirdly, during early childhood (2.1.1.3), and after that, the assessment of PA and SB will be reviewed (2.1.2). The factors associated with PA and SB during adulthood and early childhood will be presented in their aforementioned sections, yet, due to the key role in the aims of the study, the factors associated with PA during pregnancy, will be presented separately in the following chapter (2.2).

2.1.1 Physical activity, sedentary behaviour and health

2.1.1.1 During adulthood

PA in adulthood has shown associations with numerous health benefits. There is a strong evidence that physically active adults have lower rates of all-cause mortality, coronary heart disease, high blood pressure, stroke, diabetes, metabolic syndrome, colon cancer, breast cancer, and depression (Physical Activity Guidelines Advisory Committee 2008). Physically active adults have also been found to exhibit a higher level of cardiorespiratory and muscular fitness, have a healthier body mass and composition, as well as a biomarker profile that is more favourable for preventing cardiovascular disease and type 2 diabetes as well as for enhancing bone health (Physical Activity Guidelines Advisory Committee 2008). According to the PA recommendation (Physical Activity Guidelines Advisory Committee 2008, Physical Activity: Current Care Guidelines Abstract 2016), adults should do at least 150 minutes of moderate-intensity aerobic PA a week, or at least 75 minutes of vigorous-intensity aerobic PA a week, to be performed in bouts of at least 10 minutes duration. In addition, muscle-strengthening activities should be performed at least twice a week. Yet, these recommendations are met by only two-thirds of adults worldwide, (Hallal et al. 2012), and in Finland, based on a self-report, 60% of the women and 54% of the men meet the recommendation for PA (Helldán & Helakorpi 2015). Based on objective measurements, however, only 24% of the Finnish adults have been found to meet the PA recommendations (Husu et al. 2014).

SB has been identified as the fourth leading risk factor for noncommunicable diseases, and has been estimated to cause for more than 3 million preventable deaths in 2004 (World Health Organization 2009). In the review by Biswas et al. (2015), regardless of PA, SB was found to be related to risk for all-cause mortality, cardiovascular disease mortality, incidence of cardiovascular disease, cancer mortality, incidence of cancer, and incidence of type 2 diabetes. Furthermore, the risks were more pronounced at lower than at higher levels of PA (Biswas et al. 2015).

PA has commonly been divided into different domains such as leisure-time, occupation, transportation, and household activities (Pratt et al. 2004). The frequency of PA in each domain has been found to vary between countries: occupational, household, and transport are the most common PA domains in low- and middle-income countries, whereas leisure-time PA has been found to contribute more to total PA in high-income countries (Macniven, Bauman & Abouzeid 2012). Loyen et al. (2016) reported recently that people living in Northern European countries (e.g. Finland, Sweden and Netherlands) seem to be more sedentary than those living in Southern countries (e.g. Italy, Spain and Portugal). The mutual effects of PA and SB have also received increasing interest over the last few years, since some persons who meet the PA recommendations may be highly sedentary throughout the rest of the day, while some people who do not meet these recommendations may nevertheless be physically active due to their leisure-time, occupation, or household activities (Craft et al. 2012).

According to the reviews (Bauman et al. 2012, Choi et al. 2017), self-efficacy (confidence in the ability to be physically active in specific situations) was the strongest correlate of PA in adults. Furthermore, intention to exercise (Bauman et al. 2012, Choi et al. 2017), outcome expectation, perceived behavioural control and perceived fitness (Choi et al. 2017) as well as a personal history of PA during adulthood, male sex, level of education, ethnic origin and social supports were noted as positive correlates of PA (Bauman et al. 2012). Age, overweight, perceived effort (Bauman et al. 2012) and poor health or fitness were negatively associated with participation in PA (Choi et al. 2017).

2.1.1.2 During pregnancy

PA during pregnancy has numerous health benefits, and in Figure 1 the potential health benefits of PA during pregnancy have been summarized according to the evidence-based level. The evidence-based level was determined so that the consistent findings based on large population-based surveys and/or randomized controlled trials were leading to strong evidence, whereas somewhat inconsistent findings based on smaller observational studies were leading to moderate-to-weak evidence. The ACOG (American College of Obstetricians and Gynecologists 2015) has suggested that all healthy pregnant women should engage in at least 20-30 minutes of moderate-intensity PA per day on most or all days of the week. Physical inactivity (PA below the recommended level), in turn, has been reported to be an independent risk factor for maternal obesity, and additionally, for related pregnancy complications, such as GDM (American College of Obstetricians and Gynecologists 2015, Artal 2015).

GDM is defined as a type of diabetes that is initially diagnosed during pregnancy (American Diabetes Association 2000). A decrease in insulin sensitivity towards the end of pregnancy is partly a physiological phenomenon; however, in some pregnant women it may result in glucose intolerance and GDM (Kaaja & Pöyhönen-Alho 2006). Glucose metabolism tend to normalize after delivery, but the majority of women with GDM continue to be at increased risk for later type 2 diabetes and impaired glucose tolerance as well as metabolic syndrome (Feig et al. 2008, Kaaja & Greer 2005, Vohr & Boney 2008, Rich-Edwards 2009, Garcia-Vargas et al. 2012). Furthermore, women with GDM have been reported to have macrosomic newborns (birth weight ≥4000 g) and related health problems more often than their peers (Lawler et al. 2010). The offspring of the mothers with GDM are also at increased risk for developing cardiovascular disease, fatty liver and renal diseases, and impaired glucose intolerance and type 2 diabetes (Garcia-Vargas et al. 2012) as well as being overweight and at higher risk for metabolic syndrome in later life (Clausen et al. 2009).

The well-known risk factors for GDM include overweight (BMI ≥25 kg/m^2) prior to pregnancy (Zhang, Rawal & Chong 2016), while a prospective cohort study (Zhang et al. 2014) reported that more than 45% of GDM cases might have been prevented if women had adopted an overall healthy diet and lifestyle (being physically active and no smoking) and maintained a healthy body weight prior to pregnancy. The consequences of maternal overweight/obesity on maternal, fetal, neonatal and childhood morbidity have been reported in several studies (Guelinckx et al. 2008, Catalano et al. 2009, Nelson, Matthews & Poston 2010, Adamo, Ferraro & Brett 2012, Tanvig 2014). Additionally, along with various socio-demographic (e.g. high age), psychological (e.g. depression, stress), and behavioral (e.g. unhealthy diet, physical inactivity) factors, maternal overweight prior to pregnancy has been reported to be a risk factor for excessive gestational weight gain (Institute of Medicine (IOM) 2009). Excessive gestational weight gain, in turn, has been found to be an independent risk factor for maternal and offspring health outcomes, such as GDM (Hedderson, Gunderson & Ferrara 2010, Gibson, Waters & Catalano 2012), cesarean delivery (Margerison Zilko, Rehkopf & Abrams 2010, Durie, Thornburg & Glantz 2011, Jang, Jo & Lee 2011, Liu et al. 2012, Goldstein et al. 2017), operative vaginal delivery (Morken et al. 2013) as well as increased risk for large-for-gestational age births (birth weight greater than the 90th percentile for their gestational age) (Margerison Zilko, Rehkopf & Abrams 2010, Durie, Thornburg & Glantz 2011, Ferraro et al. 2012, Liu et al. 2012, Goldstein et al. 2017). Gestational weight gain below the recommended level has been related to higher risk of small-for-gestational-age births (birth weight below the 10th percentile for their gestational age) and preterm births (Goldstein et al. 2017). According to the IOM (Institute of Medicine 2009), the recommendation for gestational weight gain is 12.5-18 kg for underweight women (BMI <18.5 kg/m^2), 11.5-16 kg for normal weight women (BMI 18.5-24.9 kg/m^2), 7-11.5 kg for overweight women (BMI 25-29.9 kg/m^2), and 5-9 kg for obese women (BMI ≥30 kg/m^2). However, nowadays even 40-60% of women exceed the recommendations (Harris et al. 2015). In addition, postpartum weight retention has been found to be influenced by gestational weight gain (Nehring et al. 2011, Rode et al. 2012), which, in turn, strongly influences the development of obesity and metabolic disorders in the long term (Mamun et al. 2010, Fraser et al. 2011).

Previous studies have suggested that the downstream effects of maternal PA may facilitate beneficial adaptations to environmental stressors, which may lead to health benefits for offspring later in life (Mottola 2009, Oken 2009, Hopkins et al. 2010, May et al. 2010). The intrauterine environment plays a critical role in downstream child health, and hence there is a great need for strategies aimed at preventing childhood adiposity by increasing and maintaining maternal PA and managing maternal weight gain during pregnancy. Despite the many short- and long-term health benefits of PA for both mother and offspring, the proportion of women meeting the recommendations for PA during pregnancy ranges from 3.9% to 52.2% (Juhl et al. 2012, Gjestland et al. 2013, Santos et al. 2014, Hesketh & Evenson 2016, Richardsen et al. 2016). PA also tends to decline in frequency, duration and intensity during pregnancy (Cramp & Bray 2009a, McParlin et al. 2010, Gaston & Cramp 2011, Amezcua-Prieto et al. 2013, Hayes et al. 2015). In light of all these facts, more knowledge on the correlates of

PA during pregnancy is highly warranted to be better able to target supportive actions to the women in most need of them.

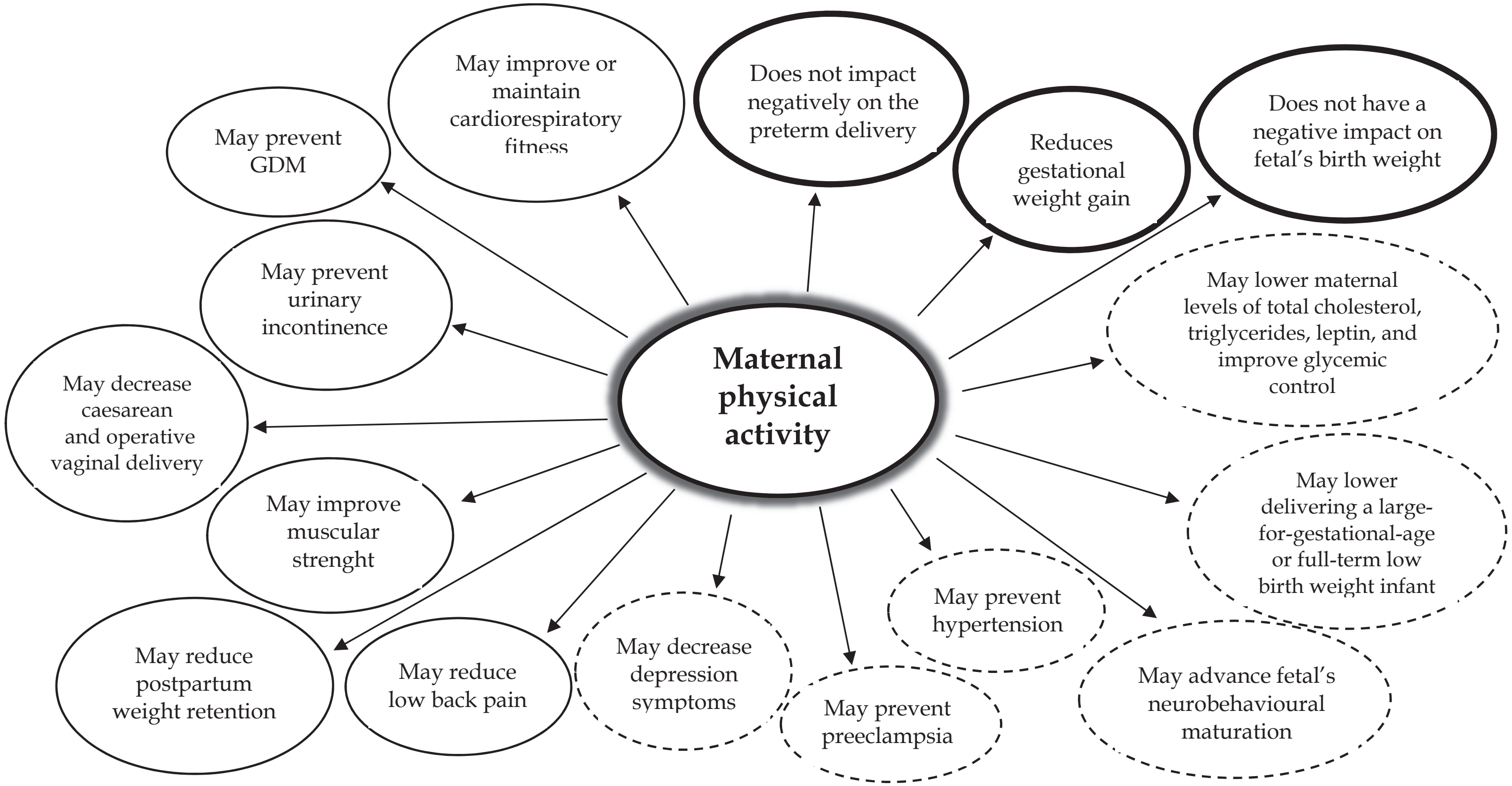
Anatomical and physiological changes occur in pregnancy that need to be addressed in the context of PA. Since weight gain increases during pregnancy, the point of gravity shifts forward resulting in progressive lordosis. Due to these changes, the forces across the joints and spine increase during weight-bearing PA (American College of Obstetricians and Gynecologists 2015). It has been reported that more than 60% of all pregnant women experience low back pain (Wang et al. 2004), and therefore, strengthening the abdominal and back muscles is recommended (American College of Obstetricians and Gynecologists 2015). Furthermore, blood volume, heart rate, stroke volume, and cardiac output normally increase during pregnancy, while systemic vascular resistance decreases, and these hemodynamic changes establish the circulatory reserve necessary to sustain the pregnant woman and her offspring while at rest and during PA (American College of Obstetricians and Gynecologists 2015). Motionless postures and the supine position have been reported to decrease venous return and hypotension in 10–20% of all pregnant women, and thus their avoidance is recommended (Clark et al. 1991). Additionally, during pregnancy, minute ventilation increases up to 50%, mostly due to increased tidal volume (Artal et al. 1986). Pulmonary reserve decreases, resulting in impaired anaerobic PA, and furthermore, subjective work load decreases during pregnancy, especially in overweight or obese women, which limits their ability to take part in high-intensity PA (Artal et al. 1986). Aerobic training during pregnancy has shown to increase aerobic capacity (Marquez-Sterling et al. 2000, Santos et al. 2005). Since temperature regulation is highly dependent on hydration and environmental conditions, to protect against heat stress, pregnant women need to stay well-hydrated, wear loose-fitting clothing and, avoid high heat and humidity (American College of Obstetricians and Gynecologists 2015). Previous studies have reported that walking, swimming and other low-impact activities are the most commonly reported types of PA during pregnancy (Owe, Nystad & Bø 2009, McParlin et al. 2010, Juhl et al. 2012).

The ACOG (American College of Obstetricians and Gynecologists 2015) recommends that the following types of PA should be avoided during pregnancy: contact sports (such as ice hockey, boxing, soccer, and basketball), PA with a high risk of falling (such as downhill skiing, water skiing, surfing, off-road cycling, gymnastics, and horseback riding), scuba and sky diving, and "hot yoga or Pilates" (American College of Obstetricians and Gynecologists 2015). Additionally, racquet sports where a pregnant woman's changing balance may affect rapid movements and increase the risk of falling should be avoided as much as possible, yet, running or jogging, racquet sports, and strength training may be safe for pregnant women who participated in these activities regularly before pregnancy (American College of Obstetricians and Gynecologists 2015). Furthermore, women should be advised to stop exercising if they have any of the following warning signs: vaginal bleeding, regular painful contractions, amniotic fluid leakage, dyspnea before exertion, dizziness, headache, chest pain, muscle weakness affecting balance as well as calf pain or swelling. Table 1 presents the relative and absolute contraindications to PA during pregnancy in all women (American College of Obstetricians and Gynecologists 2015).

TABLE 1 The relative and absolute contraindications to physical activity during pregnancy. Adapted from (American College of Obstetricians and Gynecologists 2015).

Relative
Anemia
Unevaluated maternal cardiac arrhythmia
Chronic bronchitis
Poorly controlled type 1 diabetes
Extreme morbid obesity
Extreme underweight (BMI <12 kg/m^2)
History of extremely sedentary lifestyle
Intrauterine growth restriction in current pregnancy
Orthopedic limitations
Poorly controlled hypertension
Poorly controlled seizure disorder
Poorly controlled hyperthyroidism
Heavy smoker

Absolute
Hemodynamically significant heart disease
Restrictive lung disease
Incompetent cervix or cerclage
Multiple gestation at risk of premature labor
Persistent second- or third-trimester bleeding
Placenta previa after 26 weeks of gestation
Premature labor during the current pregnancy
Ruptured membranes
Preeclampsia or pregnancy-induced hypertension
Severe anemia



The health benefits based on randomized controlled trials are enclosed in an unbroken oval, and health benefits based on observational studies are enclosed in a dashed oval. Additionally, health benefits that have reported to have strong evidence are marked in oval with thick line, and the health benefits that have reported to have moderate-to-weak evidence is marked in oval with thin line (Synthetized from Hegaard et al. 2007, Juhl et al. 2010, Price, Amini & Kappeler 2012, de Oliveria Melo et al. 2012, Han, Middleton & Crowther 2012, Jukic et al. 2012, Kasawara et al. 2012, Nascimento, Surita & Cecatti 2012, Choi, Fukuoka & Lee 2013, Domenjoz, Kayser & Boulvain 2014, Nascimento et al. 2014, Wolf et al. 2014, Cordero et al. 2015, Liddle & Pennick 2015, Muktabhant et al. 2015, Hinman et al. 2015, Russo et al. 2015, Di Mascio et al. 2016, Moyer, Reoyo & May 2016, Aune et al. 2017, da Silva et al. 2017, Forczek, Curyło & Forczek 2017, Huang et al. 2017).

FIGURE 1 Potential health benefits of the physical activity during pregnancy.

2.1.1.3 During early childhood

Regular PA in early childhood (aged <7 years) includes numerous of documented health benefits such as increased physical fitness (both cardiorespiratory fitness and muscular strength), reduced body fatness, favourable cardiovascular and metabolic disease risk profiles, enhanced bone health and reduced symptoms of depression (Physical Activity Guidelines Advisory Committee 2008, Janssen & Leblanc 2010). According to the PA recommendation for children (5–17 years) (Tremblay et al. 2016b), for optimal health benefits, the children should have at least 60 minutes of moderate-to-vigorous PA every day, and additionally, at least 3 times a week resistance exercise to enhance muscular strength, vigorous PA to improve cardiorespiratory fitness as well as to prevent cardiovascular and metabolic disease risk factors, and weight-loading PA to promote bone health. Additionally, several hours of variety of structured and unstructured light-intensity PA should be performed every day (Tremblay et al. 2016b). The Finnish guidelines for preschool children (aged <8 years), however, recommend 3 hours of PA every day, including 1-hour vigorous PA (e.g., running, cross-country skiing, swimming), 2 hours light-to-moderate PA (e.g., cycling, skating, walking in nature, balance training), while prolonged sitting periods should be avoided (Varhaisvuosien fyysisen aktiivisuuden suositukset 2016).

Furthermore, children aged 5-17 years should have SB for no more that 2 hours per day, and additionally, to limit sitting for extended periods (Tremblay et al. 2016b). Based on the IDEFICS study (Kovacs et al. 2014) of European preschool children (n=8302), 15% of all boys and 4.5% of all girls reached the recommended PA level of moderate-to-vigorous PA, whereas among the Swedish group (n=887) the corresponding amounts were 21.5 and 12.4% (Kovacs et al. 2014). Additionally, 36.6% of the European preschool boys and 43.6% of the girls did not exceed the recommended time limit for total screen time (<60 minutes/day), while the corresponding proportions among the Swedish children were 33.0 and 39.9% (Kovacs et al. 2014).

Parents play an essential role in the development of their children's lifestyle and health behaviour. Since PA and SB has found to track during early childhood and from early childhood to middle childhood (aged 6–11 years) (Jones et al. 2013), it is essential to optimize PA levels early in life. Lindsay et al. (2017) reviewed the correlates of preschool children’s PA and SB in high-income countries using a model based on the previously mentioned ecological model (McLeroy et al. 1988) that splits PA and SB into five levels: 1) intrapersonal (e.g. age, gender, material circumstances, ethnicity), 2) interpersonal (e.g. social support, networks), 3) environmental (e.g. access and proximity to parks), 4) organizational (e.g. childcare, federally funded nutrition programs), and 5) policy (e.g. state policies and regulations related to nutrition and PA in childcare settings). According to the findings, at the *individual level*, factors associated with PA included parent’s socioeconomic status (positive association), child’s sex (boys being more active than girls), family structure (children with siblings were physically more active), and cultural context (Caucasian children had higher rates of PA than African-American or Hispanic children) (Lindsay et al. 2017).

At the *interpersonal level*, the presence of siblings, single- versus two-parent families as well as the parents' culture, PA habits, attitudes toward PA, concerns about the outside environment, and their encouragement of PA were found factors influencing their children's PA. Family time spent watching television was reported to be an important negative factor impacting the PA level of young children (Lindsay et al. 2017). There are also other studies that have reported the parental factors in correlating with young children PA and SB. A review by Bingham et al. (2016) found that maternal depressive symptoms was a negative determinant (with a causal relationship) of children's PA, while a cross-sectional study by Schmutz et al. (2017) reported that increases in parental alcohol consumption and concerns regarding neighbourhood safety (based on perceptions about traffic density, road safety, crime, strangers and access to outdoor play facilities) were related to greater time spent in SB, whereas family structure (single parent status), activity temperament, parental sport club membership (at least one parent being a member) and greater time spent outdoors were related to lower time spent in SB. In addition, preschool children of older mothers have been found to reduce likelihood to be rated as physically highly active (Zecevic et al. 2010).

At the *environmental level*, outdoor space (greenness of the environment, weather and season, access to parks and PA programming as well as safety and traffic) was the primary positive factor highlighting a need for access to safe and age-appropriate places for young children to be physically active (Lindsay et al. 2017). In the context of the early care and education settings, teacher/caregiver support of PA, play equipment, and outdoor space were important positive factors associated with PA of children at the *organizational level*. At the *policy level*, however, since there is a clear PA recommendation for preschool children (National Association for Sport and Physical Education 2009) and the compliance is still low (Lessard et al. 2014), there is a lot work to do to improve PA in young children.

2.1.2 Assessment of physical activity and sedentary behaviour

PA comprises complex behaviour, which means that identifying the most precise way to capture the total level of PA presents a challenge, as different methods have different strengths and limitations (Vanhees et al. 2005). A plethora of objective and subjective techniques (such as indirect calorimetry, accelerometers, heart rate monitors, multisensors, pedometers, doubly labelled water, diaries, self-reported and interview-administered questionnaires) have been applied to assess PA in different populations, including pregnant women (Downs et al. 2012, Strath et al. 2013). The best measure to use in research will depend on the research question(s) set (Montoye et al. 2016).

Questionnaires have commonly been used to estimate the total amount of daily or weekly PA or change in PA between different time points (Salmon et al. 2007). PA questionnaires are easy to administer, relatively inexpensive and acceptable to study participants (Going et al. 1999), and therefore widely used in large-scale population surveys (Rutten et al. 2003, Bauman et al. 2009, Evenson & Wen 2010). Although objective methods such as heart-rate monitoring and accelerometers may better capture the duration and intensity of PA as well as machine learning algorithms can detect broad modes of PA, they provide no information about the type of PA behaviour or in what context or where the activity was performed (e.g. active transport, sports, school). According to the systematic review by van Poppel et al. (2010), questionnaires assessing PA in adults vary widely, and standardized PA questionnaires are lacking. As only a few questionnaires were found to possess sufficient construct validity and reliability, and no one of them was found superior to all the others, no recommendations can be made (van Poppel et al. 2010). Assessing PA by questionnaire has also been found vulnerable to under- or over-reporting, both in the general population and in pregnant women (Prince et al. 2008, Lee et al. 2011). Nevertheless, in the review by Evenson et al. (2012), self-reported PA (questionnaires and diaries) were identified with evidence of validity among pregnant women. According to their findings, the evidence for validity between diary assessments and objective measures ranged from slight to substantial, whereas the evidence for validity between questionnaires and objective measures ranged from poor to substantial. Comparison to other self-reported measures (questionnaires or diaries) were additionally found to range from fair to almost perfect agreement (Evenson et al. 2012). Physically more active pregnant women have been found to better comprehend PA intensity and duration (Brett et al. 2015), although they tended to under-estimate their PA, whereas physically inactive women tended to over-estimate their PA (Sanda et al. 2017).

Similarly, in the review of the questionnaires used to assess PA in children (mean age <18 years), Chinapaw et al. (2010) found none that had acceptable levels of both reliability and validity. During early childhood (mean age <6 years), especially, PA questionnaires did not correlate with accelerometer scores. This finding may be due to difficulties in recalling PA, the comprehensibility of the items or to differences in the activity patterns of children (Chinapaw et al. 2010). Furthermore, the focus in proxy-reporting PA in young children is on their parent or guardian, which is why agreement can be low. Therefore, observation has been additionally used (Jago et al. 2005). A recent review by Hidding et al. (2017) also found no questionnaires that were both reliable and valid in assessing SB in children. Owing to developmental differences, especially in the ability to think abstractly and to perform detailed recall, children are less likely to produce accurate self-ratings than adults (Sallis 1991, Going et al. 1999). In addition, child activity patterns are more diverse and intermittent than those of adults (Baquet et al. 2007).

The accelerometer is nowadays the most widely used method of assessing PA in both children (Hildebrand et al. 2014, Montoye et al. 2016) and adults (Montoye et al. 2016). The ActiGraph® -accelerometer (www.actigraphcorp.com) has become the most commonly used device (Wijndaele et al. 2015, Fairclough et al. 2016), and it has been extensively validated and used in PA research in children as well as adults (Cliff, Reilly & Okely 2009). The Hookie® -accelerometer (Traxmeet Ltd, Espoo, Finland), however, has been shown to be a feasible device in children at early childhood (Tuominen et al. 2016) and in adults (Vähä-Ypyä et al. 2015). Furthermore, the latest versions of accelerometers, including the ActiGraph® GT3X+ and Hookie® AM20, provide raw acceleration data expressed in gravity (g) units measured from three orthogonal axes. Such raw data allow increased control over data processing (Corder et al. 2008) and, in theory, enable comparisons between acceleration data irrespective of monitor brands. However, the use of different accelerometer brands and different placements on the body requires comparability studies for accurate interpretation of data across studies.

A few large epidemiological studies have assessed PA in both children and adults using hip-worn accelerometers (Troiano et el. 2008, Norwegian Directorate of Health 2012). However, in the latest National Health and Nutrition Examination Survey (NHANES, United States, 2011–2014), the data collection was performed using a wrist-worn device instead of the hip-worn type used in previous NHANES sweeps (2003-2006) (Rosenberger et al. 2013). The limitations of a hip-worn accelerometer include underestimation of energy expenditure during activities with little or no movement at the hip as well as the potential loss of data due to removal of the device when dressing, participating in some sports, for example in swimming, and while sleeping. Furthermore, the wrist-worn device has been found to facilitate more a long-term compliance in children and adolescents (Fairclough et al. 2016), whereas similar compliance between the hip and wrist placements was reported in large-scale studies in adults (Tudor-Locke et al. 2015). The placement of the accelerometer has additionally been found to affect measured PA levels, for example, while wrist-worn devices were found to measure higher high-intensity PA levels than hip-worn devices, the biggest difference was related to light-intensity PA (wrist-worn was measured higher levels than hip-worn) (Noonan et al. 2016). Nevertheless, hip-worn devices have been more commonly used owing to their better validity as measures of PA (Rosenberger et al. 2013), which is partly explained by their ability to capture whole-body movement (Fairclough et al. 2016). Wrist-worn devices have allowed the examination of low-intensity PA, such as arm movements during household work or when playing games (Ekblom et al. 2012). They have also shown greater sensitivity to upper body movement and less sensitivity to sedentary activities (Ellis et al. 2016). Furthermore, the wrist-worn accelerometer may present challenges when trying to accurately identify different PA intensity thresholds. When walking, jogging or running and the arms are swinging free leading to reasonably accurate information about active energy expenditure on wrist-worn accelerometer (Rosenberger et al. 2013). Yet, the motion can be rather high with little or no increase in active energy expenditure, for example, some people talk with hands and wrists remaining still, while others constantly are moving their hands and wrists, resulting in misclassification of SB (Rosenberger et al. 2013). Contrary, if the wrist is constrained from free movement during PA, such as when carrying a briefcase, talking on a mobile phone, or pushing a grocery cart, the signal from the accelerometer will be very different compared to PA when the wrist is not constrained, although the active energy expenditure would be quite similar (Rosenberger et al. 2013).

The technology of accelerometers enables data collection over short time intervals (5–15 s instead of minutes), which has been used especially in preschool children due to the belief that the PA patterns are intermittent and characterized by shorter outbursts, and therefore, short epoch lengths might capture PA more accurately (Migueles et al. 2017). However, based on a recent systematic review, there are no studies reporting the influence of different epoch lengths in children at early childhood or in adults (Migueles et al. 2017). In general, the epoch lengths have varied in previous studies from 5 s to 60 s epochs, the latter being the most commonly used (Montoye et al. 2016).

It is obvious that evaluating PA and SB is challenging, and the methods need to be always carefully considered. In addition, in promoting PA it is essential to be aware of the factors that are associated with PA and/or SB. The following section will take a closer look at the factors that influence PA and SB during pregnancy.

2.2 Factors associated with physical activity during pregnancy

More knowledge of the factors associated with PA is needed in order to be better able to promote PA during and after pregnancy. Figure 2 presents a summary of the factors that have been reported to associate with PA, stratified by consistent and equivocal evidence.

Women face numerous barriers to PA during pregnancy, and awareness of these is essential in seeking to promote PA as part of maternity care. Closed questions, rather than open-ended questions, have been the most commonly used method of identifying barriers to PA during pregnancy (Coll et al. 2017). A recent review by Coll et al. (2017) identified various barriers to leisure-time PA during pregnancy using an ecological model based on McLeroy et al. (1988). The most frequently reported *Intrapersonal* barriers to leisure-time PA during pregnancy were pregnancy-related symptoms and limitations (e.g. tiredness, feeling unwell and shortness of breath), time constraints, perceptions of already being active, lack of motivation and mother–child safety concerns; *Interpersonal* barriers were lack of advice and information and lack of social support; *Environmental, organizational and policy* barriers were adverse weather and lack of resources (Coll et al. 2017). Furthermore, in a recent multi-ethnic cohort study (Richardsen et al. 2016), physically active friends during pregnancy had a positive influence on PA.

Self-efficacy (confidence to be physically active in specific situations) has been found to be a key element in overcoming barriers and maintaining PA during pregnancy (Cramp & Bray 2009b). Moreover, PA self-efficacy and barrier self-efficacy were found to predict leisure-time PA during the second (e.g. gestation weeks 13–26) and third trimesters (e.g. gestation weeks 27–birth) of pregnancy as well as they were reported to account for up to 37% of the variance in leisure-time PA. PA self-efficacy was assessed by asking the degree of confidence in the women's ability to complete at least 30 minutes of moderate-intensity PA at frequencies of one, two, three, four, and five occasions per week. The women indicated their efficacy for each weekly PA frequency using a scale ranging from 0% to 100%. A score of 0% indicated that the participant was "absolutely not confident" in her ability to perform PA at a specific frequency, whereas a score of 100% indicated that the participant was "absolutely confident". Similarly, after listing four barriers that the women believed were likely to arise over the next weeks, participants were asked to rate their confidence to overcome the barrier using the same aforementioned self-efficacy scale. Each woman's barrier self-efficacy response set was then summed and an average was calculated to gauge their overall strength of barrier self-efficacy (Cramp & Bray 2009b).

In their review, Gaston & Cramp (2011) found that women who were physically active felt better and experienced fewer pregnancy-related symptoms. Women who rated their general health as "excellent" or "very good" were almost 2.5 times more likely to meet PA recommendations than women rating their general health as "poor" or "fair" (Evenson, Savitz & Huston 2004). Similarly, feeling good (vs. feeling unwell, tired, or depressed) has been found to associate with higher daily energy expenditure levels (Watson & McDonald 2007). In promoting PA during pregnancy, it is essential to be aware of the psychological aspect, since in Finland for example, 4.8% of all pregnant women was receiving prescriptions for antidepressants during pregnancy (Malm et al. 2012), and 0.3% of women experienced postpartum depression in 2010 (Räisänen et al. 2013).

SB during pregnancy reflects the time for being pysically active, and PA could be increased by decreasing SB. In the recent review by Fazzi et al. (2017) pregnant women were found to spent more than 50% of their time in SB, and interestingly, based on objective measures, the time spent in SB were found to be stable during pregnancy. Furthermore, increased time spent in SB was associated with higher levels of C Reactive Protein and Low-Density Lipoprotein (LDL) Cholesterol, and a larger newborn abdominal circumference, while the women who delivered macrosomic infants had a more time spent in SB (Fazzi et al. 2017). There were no significant associations found between SB and GDM, and the findings were discrepancies regarding the associations of SB with gestational weight gain, hypertensive disorders, and newborns's birth weight. SB during pregnancy has been reported to be lower among women who met the PA recommendations at 35 weeks gestation compared to women who did not (Di Fabio et al. 2015), and among women who did not smoke cigarettes in the past 5 days compared to those who did (Evenson & Wen 2011). Additionally, SB has been found to decrease more during pregnancy among women who were expecting their first baby compared to women who were pregnant for the second time (Hegaard et al. 2010) as well as among women who had completed college compared to women with less than a high school education (Lynch et al. 2012).

2.3 Body composition in early childhood

2.3.1 Assessment of body composition

Overweight and obesity are defined as “abnormal or excessive fat accumulation that presents a risk to health” (World Health Organization 2017a). According to the WHO, 39% of the world’s adults were overweight, and 13% were obese in 2014 (World Health Organization 2014). Childhood overweight and obesity, however, have increased dramatically over the last decades, and currently affect 42 million children under 5 years old globally. This figure is expected to increase to 70 million by 2025 if current trends continue (World Health Organization 2017b).

The most common way to measure obesity is to calculate BMI. In children, BMI is evaluated using age- and gender-specific charts that take into account the different growth patterns of males and females. Weight and the proportion of fat in the body differ between boys and girls, and these levels change as children grow (Cole & Lobstein 2012). BMI definitions have been found helpful for making comparisons between different population groups or monitoring a population over time (Rolland-Cachera 2011). However, BMI has been reported to fail as a measure of percentage body fat in children (Ellis, Abrams & Wong 1999) and as a means of classifying children with a high percentage of body fat when using air displacement plethysmography (ADP) (Forsum et al. 2013). An elevated BMI indicates more “overweight” than “over fatness”, and in children, a high BMI may be due to extra muscle mass (Rolland-Cachera 2011). Therefore, it has been recommended to use additional body composition measurements, such as arm and waist circumferences, skinfolds or bioelectrical impedance analysis (BIA), whenever possible (Rolland-Cachera 2011). Detailed body composition measurements, such as ADP or BIA, enables a more precise separation of body weight into fat-free mass and fat mass. Fat-free mass includes visceral protein, bone mineral and intracellular and extracellular water, while the fat-free mass index, which also takes height into account, is commonly used to assess body composition (fat-free mass (kg)/height^2 (m)). Similarly, the fat mass index can be calculated as fat mass (kg)/height^2 (m). To date, no validated cut-off points been proposed for fat-free mass, fat mass, or body fat percent to define overweight/obesity in children equal to or less than five years.

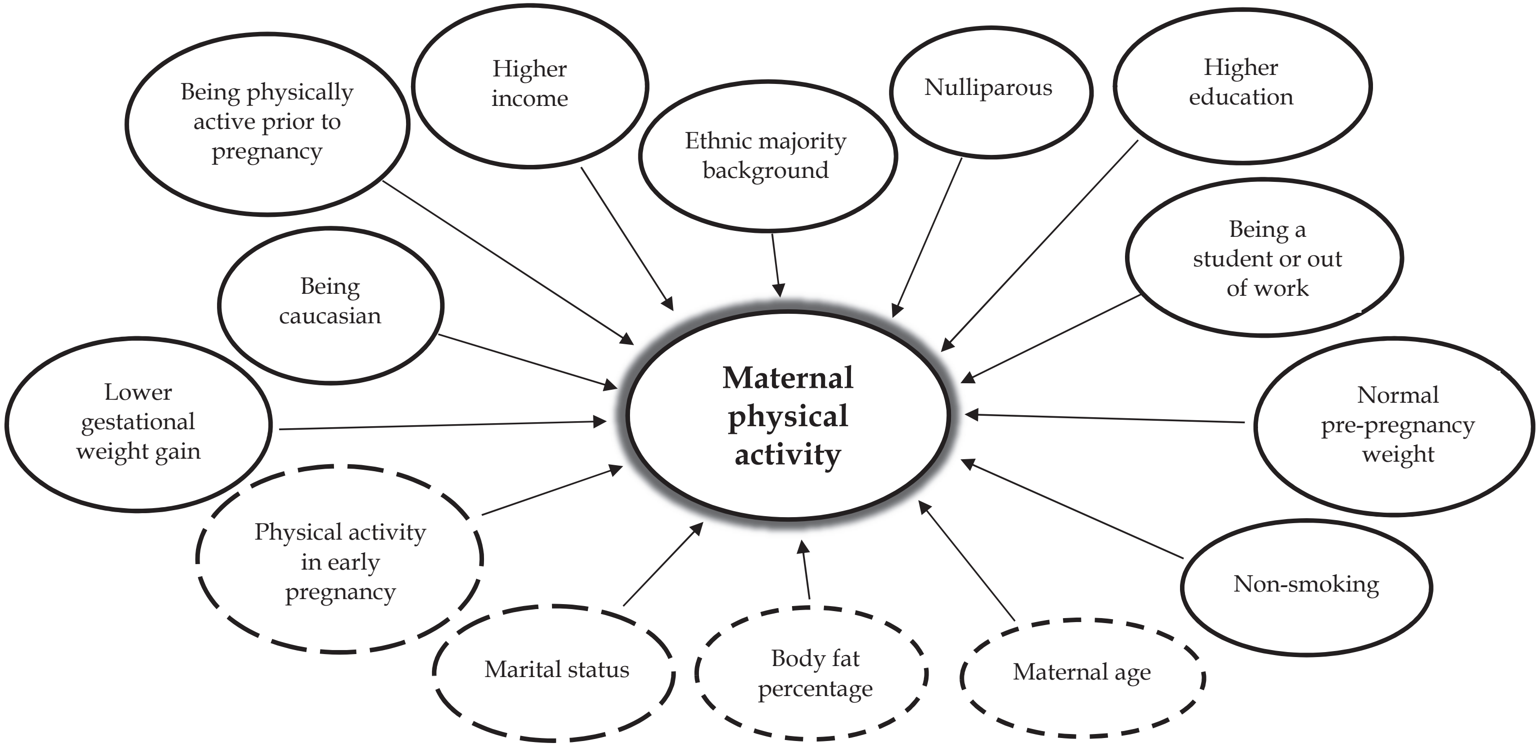
In adults, however, BMI is calculated as a person’s weight (in kilograms) divided by the square of the person’s height (in metres) (World Health Organization 2017a). Among adults in Western countries the following BMI ranges are widely used: BMI between 18.5 kg/m^2 and 24.9 kg/m^2 is deemed as normal or healthy weight, BMI greater than or equal to 25 kg/m^2 as overweight, and BMI greater than or equal to 30 kg/m^2 as obesity (World Health Organization 2017a).

2.3.2 Physical activity and obesity

Body weight (mass) and body fat distribution are elements of body composition that have implications for health. Since overweight/obesity has been associated with a wide range of serious health complications and an increased risk for premature onset of illnesses, such as diabetes and heart disease (World Health Organization 2014), it is clear that finding ways to alleviate this situation is important.

Aerobic PA has been found to affect weight maintenance due to the accumulation of energy expenditure. Resistance training, in turn, does not enhance weight loss, but instead may increase fat-free mass and decrease fat mass and is therefore associated with reductions in health risk (Donnelly et al. 2009). Among overweight and obese children, interventions focused on increasing the levels of PA have been influenced positively on health, however, interventions that aimed to increase PA in normal-weight children have found to have little influence on adiposity (Physical Activity Guidelines Advisory Committee 2008). Furthermore, it remains unclear whether physical inactivity is a contributor to obesity or vice versa (Bauman et al. 2012, Reiner et al. 2013). The evidence on whether PA prevents or attenuates detrimental changes in chronic disease risk during weight gain remains also inadequate. It should be remembered that obesity is a complex condition with multiple contributory causes, including behavioural, as well as PA-related, socioeconomic, environmental, and genetic factors (Qi & Cho 2008, Bingham et al. 2016).

Maternal pre-pregnancy BMI has been positively associated with preschool children's BMI, fat mass index, fat-free mass index and body fat percent (Castillo, Santos & Matijasevich 2015) and with children's overweight in adolescence (Pirkola et al. 2010). In the recent review and meta-analysis, Wang et al. (2017) found strong associations between obesity in both parents and obesity in their child compared to one obese parent only or to parental and child overweight. Similarly, previous studies in preschool children indicated that parental BMI correlated positively with their child's BMI and waist circumference (Sijtsma, Sauer & Corpeleijn 2015, Cadenas-Sanchez et al. 2017) as well as with fat mass index and fat-free mass index (Cadenas-Sanchez et al. 2017).



Previously reported factors associated with maternal physical activity during pregnancy. Factors for which there is consistent evidence are enclosed in an unbroken oval, and factors for which the evidence is equivocal are enclosed in a dashed oval. (synthesized from Haakstad et al. 2009, Owe, Nystad & Bø 2009, Evenson & Wen 2011, Gaston & Cramp 2011, Juhl et al. 2012, Gaston & Vamos 2013, Hayes et al. 2015, Nascimento et al. 2015, Richardsen et al. 2016).

FIGURE 2 Factors associating with physical activity during pregnancy.

2.4 Physical fitness in early childhood

Physical fitness has been defined as "the ability to carry out daily tasks with vigour and alertness, without undue fatigue and with ample energy to enjoy leisure-time pursuits and to meet unforeseen emergencies" (President's Council on Physical Fitness and Sports: Physical Fitness Research Digest 1971). Physical fitness is a set of attributes that people have or achieve, and furthermore, can be split into two groups: one related to health (a health-related) and the other related to skills that pertain more to athletic ability (a skill-related) (Caspersen, Powell & Christenson 1985). The main components of health-related physical fitness are cardiorespiratory fitness, musculoskeletal fitness and flexibility (Caspersen, Powell & Christenson 1985). Body composition has been considered a component of health-related physical fitness (Caspersen, Powell & Christenson 1985); in this dissertation, however, it has been included as a health outcome, and therefore not as a component of physical fitness. The main components of skill-related physical fitness are agility, balance, coordination, power, reaction time and speed (Caspersen, Powell & Christenson 1985).

Cardiorespiratory fitness, also known as cardiovascular fitness, aerobic fitness, aerobic capacity, aerobic power, physical work capacity, and maximal oxygen consumption, reflects the overall capacity of the cardiovascular and respiratory systems to supply oxygen during sustained PA (Taylor, Buskirk & Henschel 1955). *Musculoskeletal fitness* means that a specific muscle or muscle group is able to generate force (muscular strength) to resist repeated contractions or to maintain a voluntary contraction for a prolonged period (muscular endurance), as well as to carry out a maximal, dynamic contraction of a single muscle or muscle group in a short period (explosive strength, also known as power). Flexibility, as a part of musculoskeletal fitness, means the ability to move freely through a full range of motion using a specific muscle or muscle group. *Motor fitness* includes the components of physical fitness that are related to enhanced performance in sports and motor skills. The main components of motor fitness are agility, balance and speed. Agility is defined as the ability to rapidly change the position of the body in space with speed and accuracy, balance requires the maintenance of equilibrium while stationary or moving, and speed is the ability to perform a movement within a short given time (Caspersen, Powell & Christenson 1985). Coordination relates to the ability to use the senses, such as sight and hearing, together with body parts in performing motor tasks smoothly and accurately, and speed, is an ability to perform a movement within a short period of time (Caspersen, Powell & Christenson 1985). Physical fitness in this present dissertation is focused on the components of physical fitness that have been testing by validated physical fitness tests (Ortega et al. 2015).

2.4.1 Assessment of physical fitness

In early childhood (<7 years), cardiorespiratory fitness has been the least studied component of physical fitness, and motor fitness the most studied component. In

2014, based on a systematic review of the literature, Ortega et al. (2015) proposed the PREFIT battery, i.e., field-based FITness testing in PREschool children. The PREFIT battery comprises the following tests: the 20-m shuttle run test for assessing cardiorespiratory fitness, the handgrip strength and standing long jump tests for assessing musculoskeletal fitness, and the 4 x 10-m shuttle run and one-leg-stance tests for assessing motor fitness, i.e. speed/agility and balance, respectively. The PREFIT battery has been recognized recently as a feasible and reliable tool for assessing physical fitness in preschool children (Cadenas-Sanchez et al. 2016).

In addition to the previously mentioned tests, a few other instruments have been considered reliable in measuring physical fitness in preschool children. The ½-mile walk/run and the 3-min distance run tests (Rikli, Petray & Baumgartner 1992, Benefice, Fouere & Malina 1999) for cardiorespiratory fitness, and the sit-and-reach test for musculoskeletal fitness and flexibility (Koslow 1987) may in general be included as components of physical fitness testing.

2.4.2 Physical fitness and health

While physical fitness, particularly cardiorespiratory fitness and muscular strength, has been noted as a powerful marker of health in older children and adolescents (Ortega et al. 2008, Ruiz et al. 2009, Smith et al. 2014), very little information is available on its applicability to younger children (<6 years) (Ortega et al. 2015). Recent studies in preschool children have found a relationship between better physical fitness and healthier BMI, waist circumference (Martinez-Tellez et al. 2016, Silva-Santos et al. 2017), fat-free mass index and fat mass index (Henriksson et al. 2016). More specifically, better cardiorespiratory fitness, lower-body muscular strength and a balance test were associated with lower BMI and waist circumference, whereas better upper-body muscular strength and motor fitness were associated with higher BMI and waist circumference (Martinez-Tellez et al. 2016). Additionally, better cardiorespiratory fitness, lower- and upper-body muscular strength and motor fitness have been related to higher fat-free mass index and lower fat mass index (Henriksson et al. 2016). Furthermore, the better score in ½ -mile walk/run test has been found to correlate with lower body weight, BMI and body fat percent (Reeves et al. 1999), whereas overweight and obese preschool children were associated with poorer performance in the 20-m shuttle run test (Ebenegger et al. 2012) and in motor fitness (Silva-Santos et al. 2017) compared to normal weight peers.

2.5 Physical activity, body composition and physical fitness in early childhood

This chapter will focus on reviewing previous studies about the associations of PA and SB with body composition and physical fitness in early childhood.

Due to their influence on energy balance, the associations of PA and SB with adiposity in young children have been under growing interest over the last few years. In previous cross-sectional studies (Janz et al. 2002, Metallinos-Katsaras et al. 2007, Vale et al. 2010, Bürgi et al. 2011, Collings et al. 2013, Butte et al. 2016, Collings et al. 2017) high-intensity PA have been associated with healthier body composition in preschool children. However, the relationship between SB and adiposity remains unclear (Janz et al. 2002, Collings et al. 2013, España-Romero et al. 2013, Butte et al. 2016, Collings et al. 2017). The few studies that have examined the longitudinal associations between PA and adiposity in preschool children have reported both negative associations (Moore et al. 1995, Jago et al. 2005), no association (Metcalf et al. 2008, Bürgi et al. 2011), and in one case a positive association (Jago et al. 2005) between SB and BMI.

Previous research on the associations of PA and SB with physical fitness has focused on adults and older children, while only a few studies have examined the associations in preschool children (Bayer et al. 2009, Bürgi et al. 2011, Timmons et al. 2012). According to the cross-sectional study by Bayer et al. (2009), higher self-reported PA was positively associated with better motor fitness in German preschool children (n=12,556). Bürgi et al. (2011) investigated the relationship of PA with motor skills (agility/balance), cardiorespiratory fitness and body fat percent in preschool children (n=217), finding both cross-sectional and longitudinal associations of PA with both motor skills and cardiorespiratory fitness. Moreover, vigorous PA was related to changes in cardiorespiratory fitness over a 9-month follow-up (Bürgi et al. 2011).

Ebenegger et al. (2012) investigated differences in adiposity and cardiorespiratory fitness in Swiss preschool children (n=600) according to their weight status and sports club participation. The findings showed that overweight children and children not participating in a sports club had weaker cardiorespiratory fitness and higher body fat percent compared to their peers. Furthermore, children who did not participate in a sport club were less physically active, used media more, and they ate less healthily than children who participated in a sports club (Ebenegger et al. 2012). To date, previous studies examining the longitudinal associations of SB with physical fitness are lacking.

3 AIMS OF THE STUDY

The present study aimed to investigate the factors associated with maternal leisure-time physical activity during pregnancy and over a 7-year follow-up. A secondary goal was to examine the influence of maternal GDM risk on PA, SB and body composition among offspring in early childhood (<7 years). Furthermore, the associations of PA and SB with body composition and physical fitness in preschool children were investigated. In this study, *LTPAexHH* refers to leisure-time physical activity excluding household activities and *LTPAinHH* refers to leisure-time physical activity including household activities. Both are based on self-reports, and neither includes occupational PA. PA, and its subcategories refer to physical activity that is based on objective measurements, and thus covers all activity.

The specific aims were:

1. To investigate the factors associated with self-reported LTPAexHH during pregnancy among Finnish women at risk for GDM (Study I).

2. To investigate the difference in change in self-reported LTPAinHH from pre-pregnancy over a 7-year follow-up among Finnish women with and without GDM risk (Study II).

3. To investigate the difference in objectively measured PA at 7 years after delivery among Finnish women with and without GDM risk (Study II).

4. To investigate the influence of maternal GDM risk on PA, SB and body composition of their children at 6 years of age (Study II).

5. To investigate the cross-sectional associations of objectively measured PA and SB with body composition and physical fitness in healthy Swedish 4-year-olds (Study III).

6. To investigate the longitudinal associations of objectively measured PA and SB with body composition and physical fitness over a one-year follow-up in healthy Swedish 4-year-olds (Study IV).

4 PARTICIPANTS AND METHODS

4.1 Study designs and populations

This dissertation utilized several datasets (Figure 3) which were originally collected primarily to answer other research questions than those presented here. The participants in each dissertation study are presented in Figure 4.

Study I The cohort study comprised 399 pregnant women at risk for GDM who had been screened for eligibility to participate in a cluster-randomized controlled trial (NELLI) with the aim of preventing GDM. The women were randomized into intervention (INT) and usual care (UC) groups. Of the study group, 45.1% were assigned to UC and 54.9% to INT. INT included intensified PA and dietary counselling, which were integrated into 5 and 4 routine maternity care visits, respectively. During counselling, the participant was guided in making PA and dietary action plans that she would follow until the next visit. For the NELLI study, data were collected at three time points: at 8-12 (baseline), 26-28 and 36-37 gestational weeks (gw). Women were excluded if they had any of the following: gestational or type 1 or type 2 diabetes; inability to speak Finnish; age <18 y; multiple pregnancy; physical restriction preventing PA; substance abuse; or treatment or clinical history for psychiatric illness. In this study, the INT and UC groups were merged for the analyses. The effects of the intervention on GDM (Luoto et al. 2011) and PA (Aittasalo et al. 2012) have been previously reported.

Study II The cross-sectional and longitudinal study comprised 199 mother and child dyads. The study utilized two datasets: baseline data from the NELLI study and the NELLI 7-year follow-up data. At 7 years after the delivery, of the 788 women participated in NELLI study, 463 were not reached or they were not willing to participate, and thus, 325 were recruited to participate in the NELLI 7-year follow-up study. The dyads were included in the study if the women had responded to the PA questionnaire at 8-12 gw (baseline, regarding pre-pregnancy PA) and at the 7-year follow-up, they had at least 4 days of objectively measured

PA at the 7-year follow-up, and their children had at least 4 days of objectively measured PA at the 7-year follow-up. Of the 199 women, 56 (28.1%) participated in INT in the NELLI study, and 52 (26.1%) participated in UC. Additionally, 32 (16.1%) were excluded from the NELLI study due to GDM at the beginning of the pregnancy or dropout after the baseline measurements, and 59 (29.6%) were excluded from the NELLI study due to lack of GDM risk.

Studies III and IV The cross-sectional study (Study III) comprised 307 and the longitudinal study (Study IV) 138 children who had originally been screened for a population-based randomized controlled trial of healthy Swedish 4-year-old children (MINISTOP) (Delisle et al. 2015). The 6-month intervention consisted of a mobile phone-based application (the MINISTOP app) to help parents promote healthy eating and PA in their children. Parents were included in the study if they had a healthy 4-year-old child, were able to have their child measured at baseline (approximately at 4.5 years of age), and at least one parent could speak and read Swedish sufficiently well. Parents were excluded if their children were diagnosed with neurological or endocrine diseases, or if one or other parent suffered from a serious physical or psychological disease. In study III, baseline data before the randomization were utilized, whereas in the study IV baseline and 12-month follow-up data were utilized. Children in the control group (n=159), i.e. those who did not receive any intervention, were only included in study IV. The outcomes of the trial have been reported elsewhere (Nyström et al. 2017).

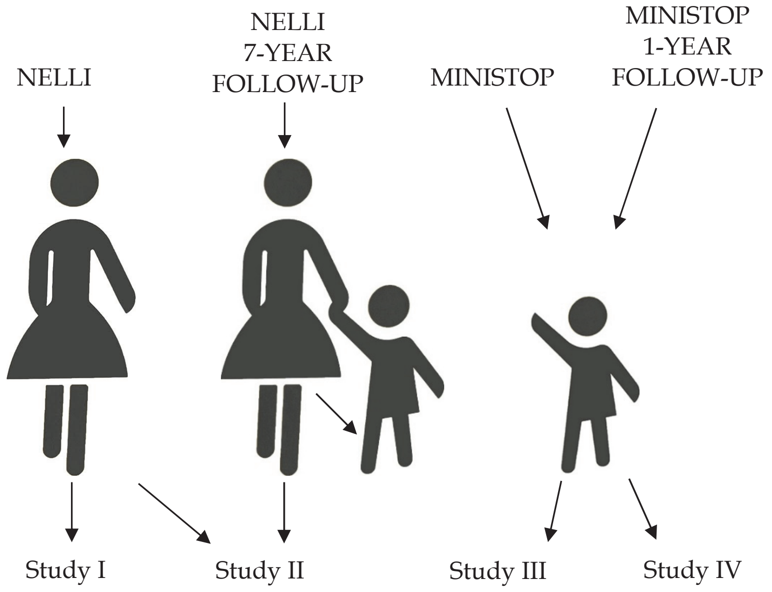
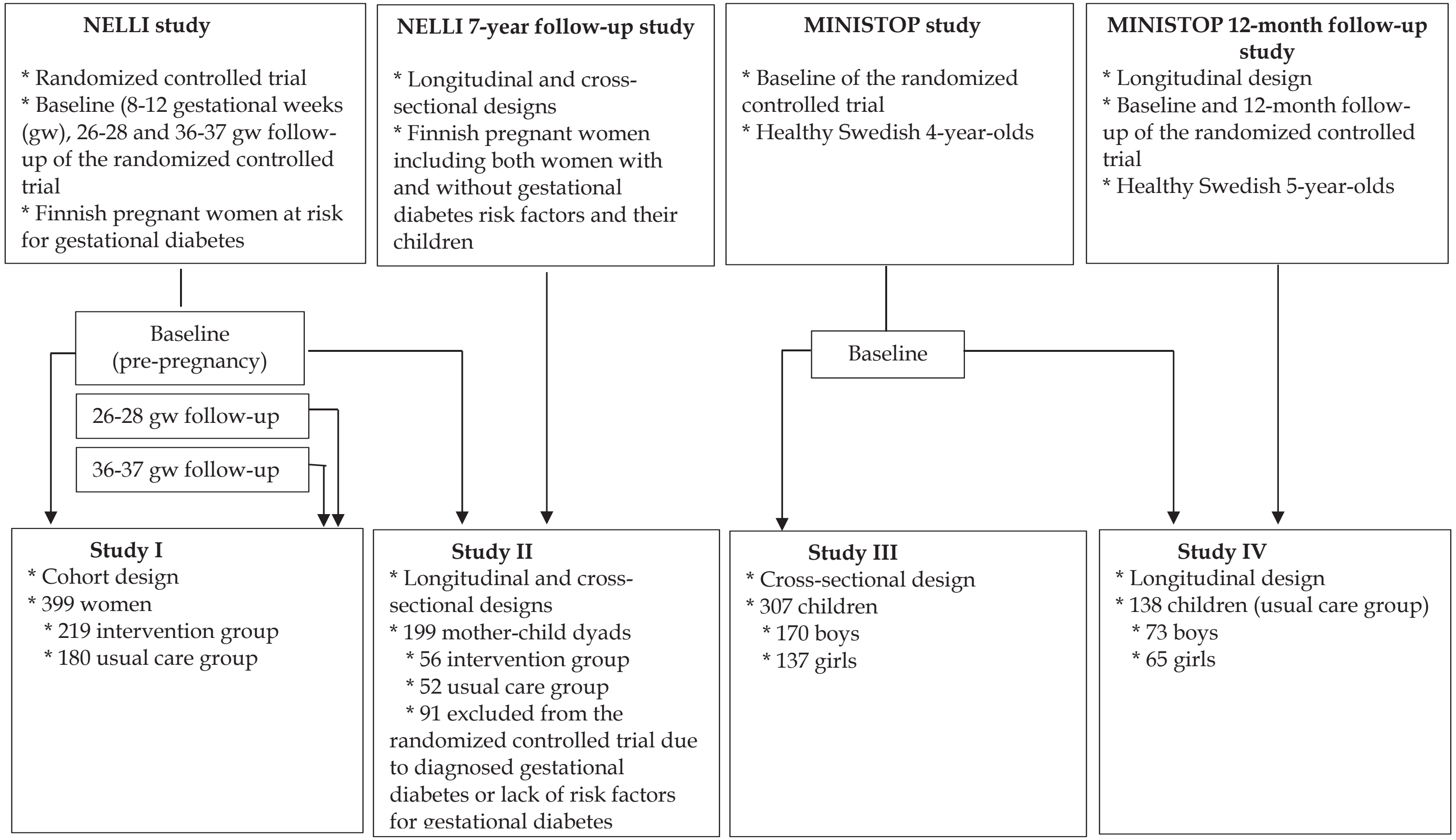


FIGURE 3 Datasets utilized in the dissertation studies.



NELLI study

- * Randomized controlled trial
- * Baseline (8-12 gestational weeks (gw), 26-28 and 36-37 gw follow-up of the randomized controlled trial
- * Finnish pregnant women at risk for gestational diabetes

NELLI 7-year follow-up study

- * Longitudinal and cross-sectional designs
- * Finnish pregnant women including both women with and without gestational diabetes risk factors and their children

MINISTOP study

- * Baseline of the randomized controlled trial
- * Healthy Swedish 4-year-olds

MINISTOP 12-month follow-up study

- * Longitudinal design
- * Baseline and 12-month follow-up of the randomized controlled trial
- * Healthy Swedish 5-year-olds

Study I

- * Cohort design
- * 399 women
  - * 219 intervention group
  - * 180 usual care group

Study II

- * Longitudinal and cross-sectional designs
- * 199 mother-child dyads
  - * 56 intervention group
  - * 52 usual care group
  - * 91 excluded from the randomized controlled trial due to diagnosed gestational diabetes or lack of risk factors for gestational diabetes

Study III

- * Cross-sectional design
- * 307 children
  - * 170 boys
  - * 137 girls

Study IV

- * Longitudinal design
- * 138 children (usual care group)
  - * 73 boys
  - * 65 girls

FIGURE 4 Description of the datasets utilized in the dissertation.

4.2 Assessments in Study I

Table 2 presents all the outcome assessments used in the studies, and Table 3 shows the PA measurements and basic characteristics of the participants. In Study I, PA was assessed with a validated self-report (Aittasalo et al. 2010) at 8-12, 26-28 and 36-37 gw, and again at 7 years after delivery (Study II only). At 8-12 gw, the questions concerned PA during a typical week prior to pregnancy and at follow-ups PA during a typical week during the past month. The questionnaire was based on the International Physical Activity Questionnaire (IPAQ), but several modifications were made in order to better distinguish the structured and unstructured features of PA (Aittasalo et al. 2010). The questionnaire was divided into two domains: 1) leisure-time PA excluding household activities, and 2) household activities only. Both domains included three intensity-specific questions (degree of breathlessness: none, some, strong) on the weekly frequency and daily duration of PA. The weekly minutes of intensity-specific PA were calculated in both domains by multiplying the number of days and minutes of daily PA. In Study I, only leisure-time PA (LTPAexHH) was taken into account, and the intensity levels, corresponding to the degree of breathlessness, were categorized as light, moderate and vigorous; moderate and vigorous were subsequently merged to form the category moderate-to-vigorous.

The factors and persons that encouraged and/or restricted the women's PA at 26–28 gw were asked using open-ended questions in order to better enable the women to express themselves. The participants were permitted to list as many factors/persons as they wished, but only the first three in each category (factors, persons) were taken for analyses. Standard maternity cards were used to collect information on the factors associated with PA at 26–28 gw. The women reported their age, body weight and height as well as background characteristics by means of a questionnaire.

4.3 Assessments in Study II

In Study II, PA was assessed in two ways: 1) based on self-report as in Study I, and 2) based on objective measurements. Self-reports were used to assess the change in PA from pre-pregnancy (baseline) to the 7-year follow-up, and objective measures to assess PA at 7 years after delivery. In Study II, unlike in Study I, the two domains of PA, leisure-time and household activities, were combined (LTPAinHH).

Data on objectively measured PA and SB were collected with a Hookie triaxial accelerometer, which has been shown to be a valid measurement tool among young people (Aittasalo et al. 2015), adults (Vähä-Ypyä et al. 2015) and preschool children (Tuominen et al. 2016). The mothers and their children were instructed to wear the waist-worn device for 7 consecutive days during waking hours, except during showering, bathing and other activities involving water. The accelerometer collected and stored raw triaxial data in g-units. Intensity of PA was estimated as mean amplitude deviation (MAD) of acceleration analysed in 6-s epochs (Vähä-Ypyä et al. 2015). The MAD value of each epoch was converted to the MET value. Cut-points were defined as follows: for SB <1.5 MET, for LPA 1.5–2.9 MET, for MPA 3.0-5.9 MET and for VPA ≥6.0 MET. In the analyses, MPA and VPA were combined to form MVPA. If the daily measurement time was over 18 hours, the participant was considered to have slept wearing the device, and thus the excess time was deducted from the time spent lying down in order to avoid possible bias in SB time.

Children's body composition was estimated using the BIA technique by TANITA (MC-780MA, TANITA Corporation, 1-14-2, Maeno-Cho, Itabashi-ku, Tokyo, Japan). Multi-frequency BIA estimated total body water, and subsequently, evaluated fat-free mass (kg) and fat mass (kg) (Kyle et al. 2004). Measurements were collected using the standard setting after manually imputing the measured height, gender, and age of the subject. The body composition measures included BMI, body fat percent (BF%), fat mass index (FMI) and fat-free mass index (FFMI). BMI was calculated as body weight (kg)/height^2 (m), and modified to correspond with the adults' BMI scale enabling classification of the prevalence of overweight and obesity (Saari et al. 2011). FMI was calculated as fat mass (kg)/height^2 (m), and FFMI as fat-free mass (kg)/height^2 (m). The women also reported their age, body weight and height as well as background characteristics by means of a questionnaire.

4.4 Assessments in Studies III and IV

In Studies III and IV, PA and SB were assessed using a wrist-worn ActiGraph wGT3x-BT triaxial accelerometer, and children were instructed to wear the accelerometer for 24h over 7 consecutive days. The monitors were set to sample at 50 Hz. Non-wearing time was determined according to van Hees et al. (2011), and the time scored as worn was classified into sleep or awake time using the Sadeh algorithm (Sadeh et al. 1991, Sadeh, Sharkey & Carskadon 1994). ActiLife software (version 6.11.2) was used to process the raw data to derive the filtered sum of vector magnitudes (VM) in 10-s epochs. The time spent (minutes/day) in intensity-specific PA levels and in SB were calculated for each child. The cut-points were defined for SB as VM ≤305; for LPA, as VM 306–817; for MPA, as VM 818–1968; for VPA, as VM ≥1969; and for MVPA, as VM ≥818 in accordance with Chandler et al. (2015). In Study III, another method of assessing PA intensities was also applied. For each child, the 25th, 50th (median), 75th, 90th and 95th percentiles of the sum of VM over units of 10 seconds during the awake time that the monitor was worn were calculated. These variables provide an estimate of the time children spent in the different intensity-specific PA percentiles (e.g. 95 %, 90 %, 75 %, 50 % and 25 % of their time) during their awake time. The advantage of these VM percentiles are that they avoid some of the limitations inherent in defining PA intensities using predefined cut-off levels.

The children's body composition was measured using a validated (Fields & Allison 2012) air-displacement plethysmography by means of the paediatric option for BodPod. Body density was evaluated from body volume and body weight, and subsequently, body fatness was calculated by applying appropriate densities for fat-free mass (kg) and fat mass (kg) (Lohman 1986). The body composition measures included were BMI, FMI and FFMI.

Physical fitness was measured using four tests from the PREFIT fitness test battery: a 20-m shuttle run test for cardiorespiratory fitness, a handgrip strength test for upper-body muscular strength, a standing long jump test for lower-body muscular strength, and a 4 x 10-m shuttle run test for motor fitness. The tests were applied twice, except for the 20-m shuttle run test which was conducted once. In the handgrip strength test, the best value of two attempts for each hand was selected, and the average of both hands was used in the analyses. For the standing long jump and the 4 x 10-m shuttle run tests, the best values of two attempts were used in the analyses. The PREFIT test battery is based on a systematic review on the reliability and validity of physical fitness tests in preschool children (Ortega et al. 2015) and has been recognized as a feasible and reliable tool in assessing physical fitness in preschool children (Cadenas-Sanchez et al. 2016).

TABLE 2 Outcome assessments in the dissertation studies.

Assessments in the studies	**Studies**			
Self-reported outcomes	I	II	III	IV
Pre-pregnancy PA	x	x		
PA during pregnancy	x			
Perceived support and barriers during pregnancy	x			
Factors associated with PA during pregnancy	x			
PA at 7-year follow-up		x		
Factors associated with PA at 7-year follow-up		x		
Objectively measured outcomes				
PA at 7-year follow-up		x		
Body composition at 7-year follow-up		x		
PA at the age of 4			x	x
Body composition at the age of 4			x	x
Physical fitness at the age of 4			x	x
PA at the age of 5				x
Body composition at the age of 5				x
Physical fitness at the age of 5				x

PA, physical activity.

4.5 Ethics of the study

In Studies I and II, all participants provided a written informed consent in accordance with the ethical principles laid down by the Finnish National Advisory Board on Research Ethics (http://www.tenk.fi/sites/tenk.fi/files/ethicalprinciples.pdf), and the studies were approved by the Ethical Committee of Pirkanmaa Hospital District. The Pirkanmaa Ethics Committee in Human Sciences provided an ethical statement approving Study II (code R14039). For Studies III and IV, an informed consent, witnessed and formally recorded, was obtained from all parents. The MINISTOP trial was registered at clinicaltrials.gov (NCT02021786) and approved by the Research Ethics Committee, Stockholm, Sweden (2013/1607–31/5; 2013/2250–32).

4.6 Statistical methods

Statistical analyses were performed using STATA (College Station, Texas: StataCorp LP) (release 12) in Study I, and SPSS (IBM, Armonk, NY, USA) in Studies II-IV (version 24 in Studies II and IV, and version 20 in Study III). In all four studies, model assumptions were examined for normality of the residuals by kurtosis and skewness values, autocorrelation of the residuals by the Durbin-Watson statistic and the multicollinearity of explanatory factors by the tolerance statistic. Outliers were detected visually in Studies I, III and IV, and in Study II using z-scores. For all analyses, a p-value of <0.05 was considered statistically significant, except for the interaction terms to control for multiple comparisons, when p<0.01 was considered as the level of significance.

In Study I, multinomial logistic regression was used to assess the association between the potential factors associated with LTPAexHH and the changes in the weekly minutes of light or moderate-to-vigorous LTPAexHH. In each case, weekly minutes were classified into three categories: 1) weekly minutes of LTPAexHH decreased >30 minutes, 2) weekly minutes of LTPAexHH were maintained (i.e. decreased <30 minutes or increased ≤30 minutes, and 3) weekly minutes of LTPAexHH increased >30 minutes. The 30 minutes cut-off points were chosen following the recommendation for pregnant women of engaging in at least 30 minutes moderate-to-vigorous PA five days a week (Physical Activity Guidelines Advisory Committee 2008). As PA usually decreases during pregnancy (Cramp & Bray 2009a, McParlin et al. 2010, Gaston & Cramp 2011, Amezcua-Prieto et al. 2013, Hayes et al. 2015), odds ratios (ORs) and 95% confidence intervals (95% CIs) were calculated using the first category as the baseline category. The predictors used in the models were age (≥30/ <30 years), BMI prior to pregnancy (<25/ ≥25 kg/m^2), education (academic/polytechnic/basic or secondary school), working fulltime (no/yes), other children under 7 years (no/yes), meeting PA recommendations prior to pregnancy (no/yes), and physically active spouse prior to pregnancy (no/yes).

Each model was adjusted for the baseline value of each specific PA outcome in weekly minutes. Since some of the pregnant women received PA counseling, the potential differences between the INT and UC groups in perceived support and barriers were analyzed by using multilevel logistic regression modelling. The group variable (INT/UC) was used as the explanatory variable, while marital status and previous childbirths were used as adjusted variables. Multinomial logistic regression was also used to assess the associations between perceived support and barriers and changes in the weekly minutes of light LTPAexHH or moderate-to-vigorous LTPAexHH in each of their three categories.

In Study II, multiple linear regression analysis was used to assess the associations of demographic characteristics with change in LTPAinHH over the 7-year follow-up and with objectively measured PA at 7-year after the delivery. In the analyses, the women were stratified by having none or having at least one risk factor for GDM. Each model was adjusted for age (continuous), BMI (continuous), education (academic/polytechnic/basic or secondary school), working status (fulltime/part-time, being a student, unemployed or on maternity leave), and number of children under 7 years in the home (at baseline: none/at least one; at follow-up: one/at least two). The analyses related to change in self-reported LTPAinHH between baseline and follow-up were additionally adjusted for baseline LTPAinHH at the corresponding intensity level. All the models related to objectively measured PA and SB were adjusted for awake wear time of the accelerometer. Since some of the women participated in the randomized controlled trial, possible differences in LTPAinHH outcomes were investigated by categorizing the participants into four groups: 1) intervention or 2) usual care group in the randomized controlled trial, 3) excluded from the randomized controlled trial due to gestational diabetes or dropout after the baseline measurements, and 4) excluded from the randomized controlled trial due to lack of GDM risk. However, this did not make any essential difference to the results, and thus results were categorized in two groups: 1) those not having any GDM risk factors and 2) having at least one GDM risk factor. Differences between groups were analysed using t-test for continuous variables due to the normality assumption, and chi-square test for the categorized variables. Furthermore, multiple linear regression models were used to examine the relationships between maternal pre-pregnancy BMI and children's objectively measured PA and body composition at the 7-year follow-up. Since a significant interaction was observed between maternal pre-pregnancy BMI and child gender and body composition outcomes, boys and girls were examined separately. All models were adjusted for child age (continuous), maternal education (academic/polytechnic/basic or secondary school), and the models for PA were also adjusted for awake wear time of the accelerometer.

In Study III, multiple linear regression was used to assess the associations of a) the 95th, 90th, 75th, 50th and 25th percentiles of VM, and b) SB and intensity-specific PA (LPA, MPA, VPA and MVPA) with the body composition measurements and physical fitness tests. First, unadjusted models were fitted after which each model was adjusted for maternal BMI (continuous), maternal educational attainment (university degree or no university degree), paternal BMI (continuous), paternal educational attainment (university degree or no university degree), child gender (boy or girl) and age (continuous) at the measurement, and awake wear time of the accelerometer (continuous). Finally, the models with SB and with the intensity-specific PA were further adjusted for other PAs: models with SB, LPA and MPA as exposures were adjusted for VPA, while models with VPA and MVPA were adjusted for SB. Gender comparisons between average values were conducted by using independent t-test for continuous variables, and chi-square test for categorized variables. Furthermore, isotemporal substitution models as described by Mekary et al. (2009) were fitted to estimate the effect of substituting one PA type with another PA type for the same amount of time (e.g. substituting LPA with MPA, by taking LPA out of the model).

In Study IV, multiple linear regression was used to assess the associations of intensity-specific PA (LPA, MPA, VPA and MVPA) and SB at baseline with the body composition measurements and physical fitness tests at the 12-month follow-up. After fitting the unadjusted models, each model was adjusted for child gender (boy or girl) and age (continuous) at the measurement time and for the awake wear time of the accelerometer (continuous) due to their potential effect on body composition and physical fitness. The models with SB, LPA or MPA as exposures were also adjusted for VPA, while models with VPA or MVPA were adjusted for SB. In addition, isotemporal substitution models were fitted when estimating the effect of substituting one PA type with another PA type at baseline on body composition or physical fitness at the 12-month follow-up. Furthermore, the associations of change in intensity-specific PA and SB with change in body composition and physical fitness between baseline and the 12-month follow-up were examined. The change values for each variable were calculated as the 12-month follow-up value subtracted by the corresponding baseline value. In the sensitivity analyses, the regression models were additionally adjusted for both maternal and paternal BMI (continuous), as well as maternal and paternal educational attainment (university degree or no university degree). Since results were not changed after including these variables, they were not included in the final adjusted models.

Supplementary analyses were performed in two different ways. First, multiple linear regression was used to assess the longitudinal association between maternal self-reported LTPAinHH (light, moderate-to-vigorous, total) prior to pregnancy and children's objectively measured PA (SB, LPA, MVPA) at 7-year after the delivery. Second, multiple linear regression was used to assess the cross-sectional association between maternal objectively measured PA (SB, LPA, MVPA) and children's objectively measured PA at 7-year after the delivery. No evidence was found for any gender interactions, and thus, the results are presented for boys and girls combined. All models were adjusted for child age and gender, maternal education prior to pregnancy, and awake wear time of the both the mother's and child's accelerometers. The regression models were additionally adjusted for maternal educational attainment, but since the results were similar, these variables were excluded from the final adjusted models.

5 RESULTS

5.1 Participant characteristics

The basic characteristics of the participants and the PA assessment methods are presented in Table 3. In Study I, more than half of the participants had previous childbirth, polytechnic education or above, were working fulltime, had other children under 7 years, were married or in cohabitation and had a physically active spouse.

In Study II, the participants were stratified into two groups according to the presence (n=152) or absence (n=47) of GDM risk at the beginning of pregnancy. The women without GDM risk had on average significantly lower weight and BMI both at baseline and at the 7-year follow-up compared to their peers with GDM risk. Moreover, a greater proportion of the women with risk factors for GDM were working fulltime instead of working part-time, or were students, employees or on maternity leave compared to the women without GDM risk factors at the 7-year follow-up (66.4 vs. 44.7%). No significant differences were observed between the groups with respect to age, height, education, marital status, the number of children at home or child background characteristics. The most frequently reported GDM risk factor was pre-pregnancy BMI ≥25 kg/m^2 (n=92, 62.5%), followed by a family history of diabetes (n=88, 57.9%), GDM or signs of glucose intolerance in any previous pregnancy (n=22, 14.5%), newborn's macrosomia in any previous pregnancy (n=4, 2.6%) and age ≥ 40 years (n=3, 2.0%). In total, 97 women (63.8%) had one GDM risk factor, 50 women (32.9%) had two GDM risk factors, and 5 women (3.3%) had at least three GDM risk factors.

In Study III, the mean age of mothers of participating children (n=307) was 36 years (SD 4.3), height 167 cm (SD 0.1), weight 68 kg (SD 12.9), BMI 24.4 kg/m^2 (SD 4.4), and 70.7% (n=217) of mothers (n= 217) had a university degree. The mean age of fathers (n=307) was 38 years (SD 5.2), height 181 cm (SD 0.1), weight 83 kg (SD 12.7), BMI 25.4 kg/m^2 (SD 3.4), and 57.3% of them (n=176) had a university degree.

In Study IV, the mean age of participating children's mothers (n=138) was 35 years (SD 4.3) at baseline height 167 cm (SD 0.1), weight 67 kg (SD 11.9), BMI 23.8 kg/m^2 (SD 4.1), and more than half of them (n=95, 68.8%) had a university degree. The mean age of fathers (n=136) was 38 years (SD 5.1), height 182 cm (SD 0.1), weight 84 kg (SD 13.0), BMI 25.4 kg/m^2 (SD 3.5), and more than half of them (n=76, 55.1%) had a university degree, respectively.

TABLE 3 Physical activity measurements and basic characteristics of the participants in the dissertation studies.

Studies	Age (years)	Body mass index (kg/m^2)	Overweight / obese (N %)	Assessment of physical activity
NELLI; Baseline				Self-reported retrospective intensity-specific physical activity questionnaire (min/week).
(Study I)				
N=399	29.7 ± 4.7	26.3 ± 4.7	166 (41.7)[1]	
(Study II)				
N=199	30.0 ± 4.8	25.7 ± 4.8	94 (47.3)[1]	
NELLI; 7-year follow-up				1) Self-reported retrospective intensity-specific physical activity questionnaire (min/week), and 2) waist-worn Hookie AM20 accelerometer (% of awake wear time).
(Study II)				
Women, N=199	37.6 ± 4.8	26.9 ± 5.6	106 (53.5)[1]	
Boys, N=107	6.5 ± 0.5	16.3 ± 0.2	26 (26.3)[2]	
Girls, N=92	6.5 ± 0.6	16.0 ± 0.2	11 (13.1)[2]	
MINISTOP; Baseline				Wrist-worn ActiGraph wGT3x-BT accelerometer (min/day).
(Study III)				
Boys, N=170	4.5 ± 0.2	15.8 ± 1.3	13 (7.6)[3]	
Girls, N=137	4.5 ± 0.2	15.7 ± 1.4	13 (9.5)[3]	
(Study IV)				
Boys, N=73	4.5 ± 0.2	15.8 ± 1.3	6 (8.2)[3]	
Girls, N=65	4.5 ± 0.2	15.4 ± 1.2	4 (6.2)[3]	
MINISTOP; 12-month follow-up				Wrist-worn ActiGraph wGT3x-BT accelerometer (min/day).
(Study IV)				
Boys, N=73	5.6 ± 0.2	15.5 ± 1.4	5 (6.9)[3]	
Girls, N=65	5.5 ± 0.2	15.2 ± 1.2	4 (6.1)[3]	

Data are shown as mean ± SD or N (%).

[1] Body mass index ≥25 (kg/m^2). [2] According to Saari et al. (2011). [3] According to Cole & Lobstein (2012).

5.2 Physical activity during pregnancy and over a 7-year follow-up (Studies I, II)

Studies I & II investigated the factors associated with self-reported LTPAexHH during pregnancy among women at risk for GDM (Study I). Additionally, the difference in change in self-reported LTPAinHH from pre-pregnancy over a 7-year follow-up and in objectively measured PA at 7 years after delivery among women with and without risk for GDM were examined (Study II).

Study I The mean weekly duration of light LTPAexHH was 179 minutes at baseline, 161 at 26-28 gw, and 179 at 36-37 gw. The corresponding amounts of moderate LTPAexHH were 130, 109, and 92 minutes, and of vigorous LTPAexHH 60, 24 and 8 minutes, respectively. Furthermore, the mean weekly minutes of moderate-to-vigorous LTPAexHH was 187 at baseline, 133 at 26-28 gw, and 99 at 37-38 gw. The most commonly reported modes of LTPAexHH throughout the pregnancy were walking, group exercise and cycling.

With respect to light LTPAexHH, the women who met the PA recommendations prior to pregnancy also had a higher probability of increasing rather than decreasing their LTPAexHH by more than 30 minutes compared with the women who did not meet the recommendations (OR 2.53, 95% CI 1.35-4.72). Similarly, the women who were working part-time had a higher probability of increasing rather than decreasing their LTPAexHH by more than 30 minutes compared with the women who were working fulltime (OR 1.89, 95% CI 0.98-3.70). For moderate-to-vigorous LTPAexHH, the women who met the PA recommendations prior to pregnancy had a lower probability of maintaining rather than decreasing their LTPAexHH by more than 30 minutes compared with the women who did not meet the PA recommendations at baseline (OR 0.36, 95% CI 0.16–0.81). Furthermore, the women who had a physically active spouse prior to pregnancy had a higher probability of maintaining rather than decreasing their moderate-to-vigorous LTPAexHH by more than 30 minutes compared with the women who had a physically inactive spouse (OR 1.81, 95% CI 1.00-3.26).

One-third of the women reported support for PA from their spouse. In addition, friends, and being in an exercise group (18.7%) as well as having a child (17.5%) encouraged them to engage in LTPAexHH. Weather-related issues (such as a good weather, fresh air, being outdoor), and having a dog were reported as encouraging factors (17.2 and 13.4%). However, more than one-fourth of the women reported that they did not received encouragement to engage in LTPAexHH from anyone during pregnancy, and one-third reported that nothing encouraged them to engage inLTPAexHH. In the usual care group, a child was more often reported as a supportive person than in the intervention group (OR 0.49, p=0.005), whereas in the intervention group weather-related issues were more often reported as encouraging factors than in the usual care group (OR 1.96, p=0.009).

The most commonly reported factors restricting engagement in LTPAexHH were tiredness, nausea and health-related issues (43.3%). Lack of time, pressure of work and having a child also restricted engagement in LTPAexHH (26.6 and 14.4%). Eight out of ten women reported that no-one and one-fifth that nothing restricted their engagement in LTPAexHH. Between intervention and usual care group, the women in the intervention group reported lack of time and work as restricting factors more often than those in the usual care group (OR 1.65, p=0.021).

The women who reported that having good company, being active together, being in an exercise group or people close to them encouraged them to engage in LTPAexHH had a higher probability of maintaining and increasing rather than decreasing their light LTPAexHH by more than 30 minutes compared to those who did not report these factors as encouraging (OR=3.5, 95% CI 1.26-9.78 and OR=3.0, 95% CI 1.07-8.45, respectively). The women who reported that tiredness, nausea and health-related issues restricted their LTPAexHH had a lower probability of increasing (rather than decreasing) their moderate-to-vigorous LTPAexHH by more than 30 minutes compared to women who did not report the same restrictions (OR=0.5, 95% CI 0.27-0.93). In addition, the women who reported work or lack of time as restrictive factors had a higher probability of increasing than decreasing their moderate-to-vigorous LTPAexHH by more than 30 minutes compared to those who did not report the same restrictions (OR=1.9, 95% CI 1.00-3.57).

Study II At baseline (pre-pregnancy), among the women without GDM risk, self-reported light LTPAinHH was on average 197 weekly minutes, moderate-to-vigorous LTPAinHH 180 and total LTPAinHH 377 weekly minutes. The corresponding values among the women with GDM risk were 183, 195, and 378 minutes. Furthermore, at the 7-year follow-up the intensity-specific weekly minutes were on average 296, 206 and 502 among the women without GDM risk, and 212, 162 and 374 among the women at GDM risk, respectively. The differences between the groups were statistically significant for self-reported light LTPAinHH (p=0.012) and total LTPAinHH (p=0.003) at the 7-year follow-up and borderline significant for self-reported moderate-to-vigorous LTPAinHH at the same time point (p=0.051). Moreover, the change in total LTPAinHH between baseline and the 7-year follow-up was significantly different between the two groups (p=0.022).

When adjusting for confounders, the results indicate that the women without GDM risk reported on average 88 weekly minutes more change in light LTPAinHH during the 7-year follow-up than the women at GDM risk (p=0.012). In addition, the change in total LTPAinHH during the 7-year follow-up in women without GDM risk was on average 130 minutes per week higher than that reported by the women at GDM risk (p=0.004). Of the confounding factors, a one-year increase in age was associated with a mean of nine weekly minutes reduction in light LTPAinHH from baseline to the 7-year follow-up (p=0.004) and twelve weekly minutes reduction in total PA (p=0.003). In addition, the mean change in light LTPAinHH (p=0.015) was 75 minutes lower among women without previous children under 7-years of age (compared to the women who had at least one previous under child under age 7).

At the 7-year follow-up the women without GDM risk spent on average 71% of their awake wearing time in SB, 19% in LPA, and 10% in MVPA. The women at GDM risk, however, spent 74% in SB, 17% in LPA, and 9% in MVPA. The differences between the groups in objectively measured LPA and SB were statistically significant ($p=0.014$ and $p=0.015$). However, after adjusting for confounders, the significant differences disappeared ($p>0.05$). Of the confounding factors, time spent in SB increased by 0.2 percentage points and time spent in MVPA decreased by 0.1 percentage points with each additional unit of BMI ($p=0.021$ and $p=0.038$). The women who had an academic education spent 4.3 percentage points more time in SB ($p=0.001$) as well as 3.0 percentage points less time in LPA and 1.3 percentage points less time in MVPA ($p<0.001$ and $p=0.045$) than those without an academic education. Furthermore, the women who were working part-time, students, on maternity leave or unemployed instead of working fulltime spent 2.0 percentage points less time in SB ($p=0.039$) and 1.7 percentage points more time in LPA ($p=0.007$).

5.3 Influence of gestational diabetes risk on children's physical activity and body composition (Study II)

Study II This study investigated whether children's objectively measured PA and/or body composition at the age of 6 differed according to whether their mothers were at risk for GDM during pregnancy. According to the results, no difference was detected in PA between groups: The children of the mothers without GDM risk (n=47) spent on average 59% of their awake wearing time in SB, 23% in LPA and 18% in MVPA. The corresponding percentages among the children of the mothers at GDM risk were on average 58, 23 and 19. However, boys spent significantly more time in MVPA compared to girls (20 vs. 18%, $p<0.001$).

No significant difference was detected regarding body compositions either. The children of the mothers' without GDM risk had BMI 16.0 kg/m^2, BF% 21.1, FMI 4.2 kg/m^2 and FFMI 15.5 kg/m^2. The corresponding means among the children of the mothers with GDM risk factors were 16.2 kg/m^2, 22.1%, 4.4 kg/m^2 and 15.4 kg/m^2. Boys had significantly lower BF% than girls (21.3 vs. 22.5%, $p=0.045$). However, of the GDM risk factors, each additional unit of maternal pre-pregnancy BMI increased boys' (n=84) BMI by 0.18 kg/m^2 ($p<0.001$), BF% by 0.29 ($p=0.001$), FMI by 0.13 kg/m^2 ($p<0.001$) and FFMI by 0.12 kg/m^2 ($p=0.002$) at the age of 6. No significant relationships were detected of maternal pre-pregnancy BMI with body composition in girls or with any of the children's PA or SB variables.

5.4 Association between physical activity and body composition (Studies III, IV)

Study III This study investigated the cross-sectional associations of PA intensities and sedentary behaviour with body composition in Swedish 4-year-olds based on a multiple linear regression models and isotemporal substitution models. There was no evidence that the associations between PA and the body composition variables were different for boys and girls, and thus, the results are reported for the whole sample (N=307). The children had SB on average 479 min/day, LPA for 261 min/day, MPA for 94 min/day, VPA for 7 min/day, and MVPA for 101 min/day. Furthermore, their mean BMI was 15.8 kg/m^2, BF% 26.0, FMI 4.1 kg/m^2 and FFMI 11.6 kg/m^2.

The multiple linear regression models showed that greater MVPA was significantly associated with lower BF%, when adjusted for confounders and SB. More specifically, 5 min/day greater MVPA was associated with 0.25 (p=0.015) lower BF%. Correspondingly, 5 min/day greater VPA and MVPA were associated with 0.19 (p=0.002) and 0.06 kg/m^2 (p=0.011) higher FFMI. In contrast, no significant associations between SB, LPA or MPA and BF% or FFMI were observed. According to the results of the isotemporal substitution analyses, substituting 5 min/day of SB, LPA or MPA with 5 min/day of VPA was associated with a 0.16-0.18 kg/m^2 higher FFMI. No statistically significant associations were observed for BMI, FMI or BF% when substituting any of the PAs.

The associations between the PA intensities as percentiles of VM (95th, 90th and 75th) and the body composition measurements showed that the 90th percentile was negatively associated with significantly lower BF% (adjusted coeff. -0.25%, p=0.047). The 95th and 90th percentiles of VM were both positively associated with a significantly higher FFMI (adjusted coeff. 0.07 kg/m^2, p<0.001; 0.08 kg/m^2, p=0.003, respectively). In contrast, no significant associations were observed between the 50th and 25th percentiles of VM and the body composition measurements.

Study IV This study investigated the longitudinal associations of the PA intensities and SB at baseline with body composition at a 12-month follow-up (N=137). At baseline, the children had SB on average 481 min/week, LPA for 261 min/week, MPA for 95 min/week, VPA for 7 min/week, and MVPA for 101 min/week. Furthermore, the mean BMI of the children was 15.6 kg/m^2, BF% 25.7, FMI 4.0 kg/m^2, and FFMI 11.6 kg/m^2.

According to the multiple linear regression models, greater VPA at the age of 4.5 years was associated with 0.39 kg/m^2 higher BMI at 5.5 one year later (p=0.005); this was due to higher FFMI (adjusted coeff. 0.36, p<0.001) and not to higher FMI (adjusted coeff. 0.02, p=0.79). Similarly, greater MVPA at the age of 4.5 was associated with 0.07 kg/m^2 higher FFMI one year later (p=0.044). No significant relationships between SB, LPA or MPA with FMI or BF% were discovered. The isotemporal substitution models showed that substituting 5 min/day of SB, LPA or MPA with 5 min/day of VPA at the age of 4.5 was related to higher FFMI one year later (p<0.001 to p=0.001) as well as to higher BMI (p=0.003 to p=0.006). In contrast, there were no statistically significant associations found for FMI or BF% when substituting any of the PAs.

Examination of the associations of change in PA and SB during one-year follow-up between 4.5 and 5.5-year-olds with the corresponding change in body composition, revealed that an increase in VPA was associated with a decrease in BF% and FMI (adjusted coeff. -0.72, p=0.004; adjusted coeff. -0.09, p=0.048). Furthermore, an increase in MVPA was associated with an increase in FFMI (adjusted coeff. 0.04, p=0.037) and a decrease in BF% (adjusted coeff. -0.22, p=0.031).

5.5 Association between physical activity and physical fitness (Studies III, IV)

Study III This study investigated the cross-sectional associations of PA intensities and SB with physical fitness in Swedish 4-year-olds. *Cardiorespiratory fitness*: Greater VPA and MVPA were both significantly associated with better performance in the 20-m shuttle run test when adjusting for confounders and SB. Specifically, 5 min/day greater VPA and MVPA were associated with 0.96 (p<0.001) and 0.24 (p<0.001) more laps, respectively. However, no significant associations between SB, LPA or MPA and number of laps in the 20-m shuttle run were observed. Furthermore, substituting 5 min/day of SB, LPA or MPA with 5 min/day of VPA were associated with a score better by nearly one lap in the 20-m shuttle run (p<0.001). *Upper-body muscular strength:* 5 min/day greater VPA was associated with a handgrip strength score higher (p= 0.042) by nearly 200g when adjusted for confounders and SB. The isotemporal substitution analyses did not reveal any significant associations when substituting one of the PA intensities with another. *Lower-body muscular strength:* 5 min/day greater VPA and MVPA were associated with a jump over three centimeters (p=0.001) and 1.2 centimeters (p<0.001) longer, respectively, in the standing long jump test. SB, LPA or MPA were not significantly associated with the standing long jump. Substituting 5 min/day of VPA with 5 min/day of SB or LPA were associated with a jump over two centimeters longer in the standing long jump test (p<0.05). *Motor fitness:* Greater VPA and MVPA were both associated with better performance (i.e. lower score) in the 4x10-m shuttle run test when adjusted for confounders and SB. More specifically, 5 min/day greater VPA and MVPA were associated with 0.67 (p<0.001) and 0.16 (p<0.001) seconds faster time, respectively. However, no significant associations between SB, LPA or MPA and the 4x10-m shuttle run test were found. Substituting 5 min/day of SB, LPA and MPA with 5 min/day of VPA was associated with a time over 0.60 seconds faster in the 4x10-m shuttle run (p<0.001).

The associations between the PA intensities as percentiles of VM (95th, 90th and 75th) and physical fitness measurements showed that the 95th, 90th and 75th percentiles of VM were associated with better performance in all the physical fitness tests, except the standing long jump test where positive associations were found only in children in the 95th and 90th percentiles of VM.

Study IV This study investigated the longitudinal association of PA intensities and SB at baseline with physical fitness at a 12-month follow-up with multiple linear regression models and isotemporal substitution models. *Cardiorespiratory fitness:* Greater VPA and/or MVPA were associated with more laps in the 20-m shuttle run test after one-year follow-up (p=0.016 and p=0.014). *Upper-body muscular strength:* Before adjusting for confounders, greater VPA was associated with a better handgrip strength score (p=0.002). However, after adjustments, the association was attenuated (p=0.083). Yet, substituting 5 min/day of SB, LPA or MPA with 5 min/day of VPA at the age of 4.5 were related to better handgrip strength at 5.5 years of age (p=0.026 to p=0.046). *Lower-body muscular strength:* Greater VPA or MVPA were associated with longer jumps in the standing long jump test (p=0.001 and p=0.023, respectively). Substituting 5 min/day of SB, LPA or MPA with 5 min/day of VPA at the age of 4.5 was associated with longer jumps at 5.5 years of age (range from p=0.002 to p=0.014). *Motor fitness:* Greater VPA and MVPA were associated with faster time in the 4x10-m shuttle run test (p=0.031 and p=0.026, respectively). When substituting any of the PAs, no statistically significant relationships changes were noted regarding cardiorespiratory fitness or motor fitness.

When examining the associations of change in PA and SB between baseline and 12-month follow-up with the corresponding change in physical fitness, increases in VPA over the follow-up period were associated with improved upper- and lower-body muscular strength (p=0.030 and p=0.033, respectively).

5.6 Association between maternal and child physical activity

In supplementary analyses, the association between maternal and child objectively measured PA was examined cross-sectionally at 7 years after the delivery (Table 4). On average, the women (n=199) spent 73% (SD 6.6) of their awake time in SB, 17% (SD 4.4) in LPA and 10% (SD 3.2) in MVPA. Their children, in turn, spent on average 59% (SD 5.8) of their awake time in SB, 23% (SD 3.2) in LPA and 19% (SD 3.9) in MVPA, and boys on average spent significantly more time in MVPA compared to girls (20 vs. 18%, p<0.001).

Based on multiple linear regression analyses, a one percentage point increase in maternal SB was related to 0.15 percentage points more time spent in SB in children (p=0.022) and 0.09 percentage points less time spent in MVPA (p=0.038). Furthermore, a one percentage point increase in maternal MVPA was related to 0.37 percentage points less time spent in SB in children (p=0.005) and 0.26 percentage points more time spent in MVPA (p=0.003) (Table 4).

When investigating longitudinal associations between maternal self-reported LTPAinHH prior to pregnancy and children’s PA at 7-year after the delivery, there were no significant findings (data not shown).

TABLE 4 Association between maternal and child objectively measured physical activity (% of awake wear time) at 7-year after the delivery (n=199).

	Child objectively measured physical activity					
	Sedentary behavior		**Light-intensity physical activity**		**Moderate-to-vigorous physical activity**	
Maternal objectively measured physical activity	**b (95% CI)**	**p-values**	**b (95% CI)**	**p-values**	**b (95% CI)**	**p-values**
Sedentary behavior						
Unadjusted	0.15 (0.02 to 0.27)	**0.020**	-0.06 (-0.13 to 0.00)	0.065	-0.08 (-0.16 to 0.00)	0.056
Adjusted	0.15 (0.02 to 0.28)	**0.022**	-0.06 (-0.13 to 0.01)	0.11	-0.09 (-0.18 to -0.01)	**0.038**
Light-intensity physical activity						
Unadjusted	-0.16 (-0.34 to 0.03)	0.093	0.09 (-0.01 to 0.19)	0.083	0.07 (-0.06 to 0.19)	0.30
Adjusted	-0.14 (-0.33 to 0.06)	0.17	0.08 (-0.04 to 0.19)	0.18	0.06 (-0.07 to 0.19)	0.35
Moderate-to-vigorous physical activity						
Unadjusted	-0.33 (-0.58 to -0.08)	**0.010**	0.11 (-0.04 to 0.25)	0.14	0.23 (0.05 to 0.40)	**0.011**
Adjusted	-0.37 (-0.62 to -0.11)	**0.005**	0.11 (-0.04 to 0.25)	0.14	0.26 (0.09 to 0.43)	**0.003**

Multiple linear regression models adjusted for child gender and age at measurement, maternal education (academic/polytechnic/basic or secondary school), and awake wearing time of the accelerometers. Coefficients (95% confidence intervals) and p-values.

6 DISCUSSION

The present dissertation investigated the factors associated with self-reported LTPAexHH during pregnancy among women at risk for GDM, the influence of GDM risk on the women's self-reported LTPAinHH and objectively measured PA in long-term, and on their children's PA and body composition in early childhood. Also, the associations of preschool children's PA and SB with their body composition and physical fitness were examined. This dissertation additionally investigated whether mothers' PA is cross-sectionally and/or longitudinally related to their children's PA at 7 years after the delivery.

Previous studies examining PA during pregnancy have mostly focused on women in general (Coll et al. 2017) or on women with diagnosed GDM (Retnakaran et al. 2010). The findings of this study, however, suggest that the factors associated with LTPAexHH among women at risk for GDM are consistent with the correlates of PA among women in the general population (Joseph et al. 2015, Coll et al. 2017). Furthermore, maternal GDM risk did not seem to influence children's PA or body composition in early childhood, even though the women at risk for GDM increased their self-reported LTPAinHH between pre-pregnancy and the 7-year follow-up significantly less than the women without GDM risk. Of the GDM risk factors, maternal pre-pregnancy BMI was related to unhealthy body composition in boys at the age of 6. Since the prevalence of GDM risk factors among pregnant women have increased (Vuori & Gissler 2016), this knowledge in this specific target group is clearly needed. This study used accurate and up-to-date methods in assessing PA, body composition and physical fitness in early childhood. According to the findings, high-intensity PA was strongly associated with healthier body composition and better physical fitness. Childhood obesity has been nominated one of the most serious public health challenges of the 21st century (World Health Organization 2017b), and the Commission on Ending Childhood obesity (Nishtar, Gluckman & Armstrong 2016) indicated reducing the risk of obesity in critical periods in the life-course such as pregnancy, infancy and early childhood as one of their strategic objective. This study contributes to efforts to meet these challenges by providing information on the longitudinal associations of maternal pre-pregnancy BMI and children's body composition as well as associations of children's PA and body composition in early childhood that can be used in interventions aimed at preventing the accumulation of fat mass early in life.

6.1 Physical activity during pregnancy and over a 7-year follow-up

Among the women at risk for GDM, self-reported LTPAexHH decreased and shifted from high-intensity to low-intensity during pregnancy, which is in line with the previously published findings (Cramp & Bray 2009a, McParlin et al. 2010, Gaston & Cramp 2011, Amezcua-Prieto et al. 2013, Hayes et al. 2015, Forczek, Curyło & Forczek 2017). The most popular type of LTPAexHH was walking, as also found in previous studies (Ning et al. 2003, Owe, Nystad & Bø 2009, McParlin et al. 2010, Amezcua-Prieto et al. 2013, Nascimento et al. 2015). However, in this specific study group cycling, jogging and group exercise were also popular types of LTPAexHH. The intensities of the above-mentioned types of PA are easily modifiable, and therefore may be favoured by pregnant women.

Working part-time, meeting the PA recommendations prior to pregnancy or having a physically active spouse prior to pregnancy were, again in line with the previous studies, related to higher LTPAexHH. The finding for part-time work possibly reflects the fact that these women had more time for LTPAexHH, since lack of time has been a commonly reported barrier to PA (Joseph et al. 2015, Coll et al. 2017). Additionally, Juhl et al. (2012) reported in the large Danish National Birth Cohort -study that women who were students or out of work were physically more active than those who were working. Therefore, part-time work and/or flexible working hours could be recommended for pregnant women, allowing them to save their time and energy for maintaining their PA. Furthermore, the positive impact of PA prior to pregnancy on PA during pregnancy has also been noticed in other studies (Ning et al. 2003, Haakstad et al. 2009, Owe, Nystad & Bø 2009, Da Costa & Ireland 2013, Nascimento et al. 2015), thereby highlighting the need to promote a physically active lifestyle among women at the onset of childbearing age. Nevertheless, according to the results of this study, the women who met PA recommendations prior to pregnancy were more likely to decrease their self-reported moderate-to-vigorous LTPAexHH during pregnancy compared to the women who did not meet the PA recommendations. The explanation for this finding may be that the physically more active women replaced moderate-to-vigorous LTPAexHH by light LTPAexHH. Moreover, a physically active spouse was related to higher LTPAexHH during pregnancy, a finding also in line with the previous research (Richardsen et al. 2016, Coll et al. 2017). Moreover, almost half of the women cited their spouse as supportive of their LTPAexHH, and one-third of the women cited their spouse as a primary support for LTPAexHH during pregnancy. These findings indicate that social support, especially from the closest people and from physically active friends are essential for overcoming the barriers to PA during pregnancy. This is a finding that should be noted by maternity clinics.

More than one-fourth of the women reported that no-one encouraged them to engage in LTPAexHH during pregnancy, and one-third reported that nothing encouraged them to engage in LTPAexHH. More than three-quarters of the women reported that no-one restricted them to engage in LTPAexHH, and less than one-fifth of the women that nothing prevented them from engaging in LTPAexHH. Interestingly, only 13 of the 399 of the women reported encouragement to engage in LTPAexHH from health care professionals. It may, however, reflect the limited appoitment time the nurses had with the pregnant women. Furthermore, the questionnaire was very closely related to the intervention and the women may have thought that they were expected to point to persons from outside maternity care services. Nevertheless, the findings of this study are in line with the recent review by Coll et al. (2017), who also found that lack of social support as well as lack of advice and information were barriers to LTPA during pregnancy. Health care providers have been found to give little or no advice about PA during pregnancy (Coll et al. 2017), possibly owing to constraints on time, as already mentioned. A qualitative study among 58 African American, Caucasian, and Hispanic pregnant women of varying body sizes concluded that pregnant women need clearer and more individualized guidance from health care professionals regarding dietary choices and PA on several occasions throughout their pregnancy (Ferrari et al. 2013). A Brazilian cross-sectional study among 1,279 women by Nascimento et al. (2015) found that receiving PA guidance during pregnancy was associated with higher PA. These facts highlight the role of support and specific PA guidance during pregnancy by health care providers.

The women without GDM risk at the beginning of pregnancy increased significantly more their self-reported LTPAinHH from pre-pregnancy during the 7-year follow-up compared to the women at GDM risk. The women without GDM risk may have had an overall healthier lifestyle and been generally more physically active, which makes continuing with LTPAinHH after delivery easier. Nevertheless, opposite findings have been reported among overweight/obese women (Evenson, Herring & Wen 2012) as well as among women who have been diagnosed with GDM (Retnakaran et al. 2010); however, these findings are not comparable owing to differences in the lengths of follow-up periods and in the questionnaires used to assess PA.

Regarding self-reported moderate-to-vigorous LTPAinHH, the women without GDM risk increased it more over the 7-year follow-up compared to their counterparts at GDM risk, yet, the difference was non-significant. It is possible that the number of the women without GDM risk (n=47) may be too small to indicate the statistically significant difference, and additionally, the wide range in standard deviations was likely to effect on the findings. Nevertheless, since BMI has been found to effect on the difference between absolute PA intensities and PA intensities relative to individual fitness level (Kujala et al. 2017), the finding of the present study is relevant. Overweight/obese women may have had similar reported moderate-to-vigorous LTPAinHH level over the 7-year follow-up as the normal weight peers, although the absolute moderate-to-vigorous LTPAinHH levels may have been different (was not measured). This point of view is essential in promoting PA among overweight/obese women, and highlights the need to relate the recommended PA to individual fitness.

The results in Study II indicated that women who did not have previous children (aged <7 years) as well as increase in age were associated with less change in LTPAinHH from pre-pregnancy to the 7-year follow-up. Study I also supports these findings indicating that previous child encouraged pregnant women to be physically more active. It was also observed that health-related issues, such as tiredness and nausea, restricted the women's LTPAexHH during pregnancy. It is possible that older women perceived their health as weaker, leading them to reduce their level of LTPAinHH during and after pregnancy.

No significant differences were observed cross-sectionally in objectively measured PA or in SB between the women with and without GDM risk at 7-year after the delivery. It is also noteworthy that 152 out of 199 women (76.4%) had at least one GDM risk factor, and that 51 of them (33.6%) were diagnosed with GDM later during pregnancy. Therefore, the result is encouraging and suggests that whether the women have GDM risk at the beginning of pregnancy or are diagnosed with GDM during pregnancy, their PA and SB may be on the same level as that of their peers without such risk seven years later. On the other hand, it is always possible that the most inactive women declined to participate in this PA study, and this may have biased the results.

This study (Study II), also investigated the factors associated with objectively measured PA and SB at the 7-year follow-up. The results showed that higher BMI, having an academic education and/or working fulltime instead of working part-time, being a student, being on maternity leave or being unemployed were negatively related to time spent in LPA and positively related to time spent in SB. Herman & Saunders (2016) reported that people with higher education are more likely to sit for longer due to their occupation. Since the elevated health risks related to SB are well known (Biswas et al. 2015), paying more attention to these target groups is warranted, to reduce both the time spent in SB and the adverse health outcomes of SB.

6.2 Influence of gestational diabetes risk on children's physical activity and body composition

There is a lack of previous studies examining the long-term influence of maternal GDM risk on child health. In this study, however, no statistically significant differences were found in children's PA or SB stratified by their mother's GDM risk. Similarly, none of the maternal GDM risk factors were found to make any difference to the level of PA or SB between these two groups at 6 years of age. Other factors, such as parental PA or SB (Ferreira et al. 2007, Xu, Wen & Rissel

2015) and education (Ferreira et al. 2007, Muthuri et al. 2016) are likely to have a stronger impact on children's PA and SB. However, according to the previous studies, it seems that maternal current BMI is negatively related to children's PA (Butte et al. 2014, Muthuri et al. 2016) and positively to children's SB (Butte et al. 2014). Therefore, it is likely that a mother's current BMI affects her children's PA in early childhood more than her pre-pregnancy BMI. Furthermore, high pre-pregnancy BMI may be more related to overnutrition, and hence, influences children's adiposity rather than PA or SB.

The lack of a significant difference in body composition at 6 years of age between the two groups of children, borned to mothers' with or without GDM risk factors, may be due to the "natural course" in all the participating mothers, meaning that participating in the study may be motivating itself and lead to improvements in lifestyle. To date, no other studies have investigated these relationships in the same way, hence there is no comparable data. A positive association between GDM in mothers during pregnancy and obesity in school-aged offspring (9-11 years) later has been reported (Lawlor et al. 2010, Zhao et al. 2016). However, mothers' current BMI (Zhao et al. 2016) and BMI prior to pregnancy (Lawlor et al. 2010) have been found to strongly affect the results. The supplementary analyses of this study confirmed the previous findings, as a positive relationship was found between maternal pre-pregnancy BMI and children's body composition (BMI, BF%, FMI and FFMI) later at 6 years of age. However, the findings only concerned boys, and thus run contrary to the results of previous studies (Berkowitz et al. 2005, Catalano et al. 2009, Pirkola et al. 2010, Castillo, Santos & Matijasevich 2015). These somewhat differing findings may be due to different study designs and different ethnic and genetic backgrounds (Castillo, Santos & Matijasevich 2015). Shared genetic factors may also contribute to the association between mothers' pre-pregnancy BMI and boys' body composition. Nevertheless, the population-based Northern Finland 1986 Birth Cohort study (Vääräsmäki et al. 2009) (n=4,004) found over a 16-year follow-up that the prevalence of overweight children was higher among mothers with GDM, and that their children also had a higher waist circumference independently of birth weight, preterm birth, or later overweight. A significant proportion of the adolescents also met the criteria for metabolic syndrome, particularly those born to mothers with GDM (Vääräsmäki et al. 2009). All these findings highlight the role of maternal BMI prior to and after pregnancy, in addition to diagnosed GDM or the other GDM risk factors, in preventing childhood overweight/obesity, and hence they should be highly noted in health promotion. Since family lifestyle has been reported to improve children's PA (Butte et al. 2014), future studies are needed to clarify the maternal factors influencing children's PA in order to be better able to support the "teachable moment" during pregnancy.

6.3 Association between physical activity and body composition

One of the main aims of this study was to examine the cross-sectional (Study III) and longitudinal (Study IV) associations of PA and SB with body composition in preschool children using accurate and up-to-date methodology and contribute to filling the gap in the literature. Previous studies have mostly utilised subjective measurements of PA and SB and rough measurements of body composition, such as BMI, which has not been found an accurate instrument in children.

Our principal finding was that VPA at the age of 4.5 years was related to higher FFMI in both the cross-sectional analyses and over the one-year follow-up. Due to the present precision of the measurement of body composition, contrary to previous studies (Moore et al. 1995, Jago et al. 2005, Metcalf et al. 2008, Bürgi et al. 2011), it was possible to separate fat-free mass from fat mass in order to produce novel findings. Furthermore, greater VPA at age 4.5 was positively related to BMI at 5.5 years of age. Since VPA was longitudinally related to higher FFMI, but not FMI, the findings indicate that the relationship between VPA and BMI was a reflection of the relationship between VPA and FFMI. As previously stated by Rolland-Cachera (2011), high BMI in children may be due to extra muscle mass.

Both the cross-sectional and longitudinal analyses showed that SB was not related to body composition, which is consistent with the results of a previous study (Collings et al. 2013). Conflicting results have also been reported (Janz et al. 2002, Jago et al. 2005); these may be due to methodological differences, since in previous studies SB has been based on parental self-report. However, the relationship between SB and body composition may be indirect, since time spent in SB is time not spent in PA, and, as the evidence suggests, time spent in PA may support healthy body composition. In addition, SB, such as TV viewing, has been associated with a higher energy intake already in young children (Hobbs et al. 2015). Although, SB can also be activities such as reading a book or painting, which may not be associated with a higher energy intake. Thus, in future studies, it is essential to investigate more carefully the associations of different types of SB with body composition. Furthermore, the role of breaks in SB on body composition as well as on other health outcomes should be additionally further examined. According to the isotemporal substitution analyses in the present dissertation (Studies III & IV), replacing 5 min/day of SB with 5 min/day of VPA was related to higher FFMI in both the cross-sectional and longitudinal designs. These findings support the view that SB may be indirectly related to body composition via PA.

Study III showed that MVPA was related negatively to BF% and positively to FFMI at 4.5 years of age. Replacing 5 min/day of SB, LPA or MPA with 5 min/day of VPA was also associated with higher FFMI. Comparing these results against the previous ones is somewhat difficult due to differences in the methodology applied to determine PA and body composition. However, Collings et al. (2013) found negative associations of VPA and MVPA with total adiposity but no association between PA and FFMI. Janz et al. (2002) also found negative associations between VPA and BF% and a positive association between MVPA and FFMI, although only in girls. One possible reason for the somewhat different results obtained for FFMI is that in the present study PA was assessed using a triaxial accelerometer and shorter epoch lengths, which have been found to capture PA more precisely, and can thus be recommended for use with young children (Cliff, Reilly & Okely 2009).

A further advantage of this study is the use of VM percentiles in the analysis of the accelerometer data, a methodological choice which enabled to estimate the time spent by the children in intensity-specific PA percentiles (e.g. 95 %, 90 %, 75 %, 50 % and 25 % of their time) during their awake time. The use of VM percentiles may overcome some of the limitations inherent in defining PA intensities using predefined cut-off levels. However, in this case, the results based on cut-points and on VM percentiles were consistent and the findings corroborated each other.

As found in the cross-sectional analyses (Study III), MVPA at the age of 4.5 was related to higher FFMI at one year later in the longitudinal analyses (Study IV). Moreover, SB at the age of 4.5 was not related to any of the body composition measurements one year later. However, replacing 5 min/day of SB, LPA or MPA with VPA were related to higher FFMI and BMI at 5.5 years of age. To conclude, the cross-sectional findings at 4.5 years of age and the longitudinal findings from 4.5 to 5.5 years of age, are consistent and also highlight the role of high-intensity PA in supporting healthy body composition in young children.

In Study IV, the associations of the change in intensity-specific PA and SB with the body composition measurements over the one-year follow-up were also investigated. The analyses showed that, irrespective of the baseline PA level, increasing high-intensity PA between 4.5 and 5.5 years of age was associated with improved body composition one year later. These findings support our main conclusion and also underline the need to increase high-intensity PA in order to decrease BF% and FMI in young children.

6.4 Association between physical activity and physical fitness

Knowledge on the cross-sectional or longitudinal associations of PA and SB with physical fitness in preschool children is lacking. Hence, the aim of this dissertation was to examine these associations by assessing PA, SB and physical fitness as accurately as possible by means of a validated test battery inclusive of all the four components of physical fitness. The findings were consistent and indicated that high-intensity PA at 4.5 years of age was related to better physical fitness scores both cross-sectionally and longitudinally at the one-year follow-up. These results contribute importantly to the existing literature, since these relationships have been little studied previously.

To the best of the knowledge, Study III was the first study to investigate the associations of accelerometer-derived PA with all components of physical fitness in preschool children. The results showed that VPA was strongly related to all four components of physical fitness (i.e. cardiorespiratory fitness, lower- and upper-body muscular strength, and motor fitness). Additionally, MVPA was related to all the physical fitness test outcomes, except for upper-body muscular strength, where the relationships were clearly weaker. The results are in line with reports on the associations between PA and single fitness tests in preschool children (Bayer et al. 2009, Bürgi et al. 2011). In the study by Bayer et al. (2009), based on a self-report assessment, high-intensity PA was positively associated with the number of jumps in a motor test in preschool children, while Bürgi et al. (2011) found that VPA was associated with both motor skills and cardiorespiratory fitness. The authors also found that VPA was related to changes in cardiorespiratory fitness over a 9-month follow-up in preschool children (Bürgi et al. 2011). Furthermore, Ebenegger et al. (2012) found that participating in a sport club was associated with cardiorespiratory fitness in preschool children. The present results confirm these previous findings, and extend the literature by providing data on the relationships between PA and muscular strength.

SB was not related to physical fitness in either the cross-sectional or longitudinal analyses (Study III & IV). However, it is possible that the relationship is indirect, meaning that a decrease in the time spent in SB, and thus a concomitant increase in the time spent in PA, may be related to better physical fitness. That is supported by cross-sectional findings (Study III), where replacing 5 min/day of SB with 5 min/day of VPA was related to better scores in all the physical fitness tests, except handgrip strength (upper-body muscular strength). The lack of a significant finding for upper-body muscular strength may be explained by the weaker relationship between VPA and upper-body muscular strength than with the other fitness tests. However, in the longitudinal analyses (Study IV), replacing 5 min/day of SB with 5 min/day of VPA at the age of 4.5 was related to better scores in the handgrip strength and standing long jump tests (upper- and lower-body muscular strength). These results support the previous interpretation that the positive relationship between VPA with BMI reflected higher fat-free mass instead of fat mass, given the strong relationship between FFMI and physical fitness in preschool children (Henriksson et al. 2016).

In Study IV, the supplementary analyses indicated that, irrespective of the baseline PA level, an increase in VPA between 4.5 and 5.5 years of age was related to improvements in upper- and lower-body muscular strength. These results support the main findings, and additionally, emphasize the need to increase VPA in order to improve physical fitness at early ages.

6.5 Association between maternal and child physical activity

The relationships of maternal PA and SB with their children's PA and SB was examined in a cross-sectional design at 7-year after the delivery. According to the results, maternal SB was positively related to children's SB and negatively to

MVPA at 7-year after the delivery, whereas maternal MVPA was negatively related to children's SB and positively to MVPA. These findings are in line with previous studies (Ferreira et al. 2007, Xu, Wen & Rissel 2015, Sigmund et al. 2016, Barkin et al. 2017), and even more strongly highlight the connection between maternal and child PA. Sijtsma, Sauer & Corpeleijn (2015) in turn found no association of higher maternal total PA levels with their children's total PA level but instead with their children's MVPA. In contrast, Erkelenz et al. (2014) reported no association between parental and children's PA levels based on self-report in 1,615 German 7-year-olds. However, they found that children who had at least one active parent had higher participation in organised sports. The results indicate that parental support for PA in children may be more important than parents as a role model. Likewise, the importance of parental support and encouragement in promoting children's PA was highlighted in the review by Xu, Wen & Rissel (2015).

This study also investigated the longitudinal association between maternal self-reported LTPAinHH prior to pregnancy and children's PA at 7-year after delivery, and the associations were non-significant. The results indicate that maternal present PA may be more relevant in supporting children's PA than the maternal PA prior to pregnancy. However, this finding extends the literature on the long-term effect of maternal pre-pregnancy PA on children's PA, yet, requesting further studies to confirm the results.

6.6 Methodological considerations

The major strength of this dissertation is the large number of pregnant women at risk for GDM and the long follow-up period (Studies I & II). Increasing knowledge on leisure-time PA in this risk group can help health care professionals to optimize PA promotion before and during pregnancy. In addition, awareness of the factors that associate with maternal PA during pregnancy is essential in order to better target interventions on this issue. Perceived support and barriers were collected using open-ended questions, instead of the closed questions that are more commonly used (Coll et al. 2017), thereby enabling more spontaneous responses from the women, and hence a fuller picture of their perceptions of support for and barriers to their PA (Study I). To the best of the knowledge, this is the first study to examine the influence of GDM risk on women's PA longitudinally along with their children's PA, SB and body composition in early childhood (Study II). PA and SB were measured using a triaxial accelerometer, which collects data in raw mode, and has been shown to be a valid device in assessing PA and SB (Aittasalo et al. 2015, Vähä-Ypyä et al. 2015, Tuominen et al. 2016).

It is relevant to note that some of the women received PA and dietary counselling during pregnancy (Studies I & II). Counselling has been reported to be effective in maintaining the weekly frequency of total and moderate-to-vigorous LTPAexHH during pregnancy but not effective in increasing the weekly duration of LTPAexHH (Aittasalo et al. 2012) or reducing maternal GDM (Luoto et al. 2011). However, counselling was found to be effective in slowing children's weight gain in the pilot study (Mustila et al. 2012), in which the sample size was smaller (n=89), and the follow-up period was only one year. Although participation in the intervention was taken into account in the analyses due to its potential confounding effect, it made no essential difference to the results.

As common in research, the participating women may have received "a natural course", which may have affected the results. The number of women without GDM risk was rather small, which may have produced lack in statistical power in the analyses. In future studies, a larger number of women without GDM risk would be needed. The assessment of PA was based on self-reports (Studies I & II), which is vulnerable to under- or over-reporting. However, the questionnaire was the same at every measurement point, and therefore misreporting was likely to occur consistently each time. The questionnaire has been validated in pregnant women (Aittasalo et al. 2010), and the validity of self-report as a valid tool in assessing PA among pregnant women has been demonstrated in a few studies (Evenson et al. 2012). In the analyses, PA was defined both as LTPA excluding household activities (Study I) and as LTPA including household activities (Study II), while occupational PA was not analysed at all. This may have led to biased results, since some women may be physically active at work but physically inactive during their leisure-time (Craft et al. 2012). On the other hand, occupational PA may not have played a notable role in our study, since one-fourth of the women did not work and every third mostly worked in a sitting position. Leisure-time PA has been reported to contribute the most to total PA in high-income countries (McNiven, Bauman & Abouzeid 2012). Maternal pre-pregnancy weight was based on self-reports, which may have led to underestimation, and further, to underestimation of pre-pregnancy BMI. For this reason, the number of overweight women may be higher. Finally, the use of BIA to measure body composition in preschool children has been reported to underestimate BF% (Delisle Nyström et al. 2016). However, at the time the NELLI study was initiated, more accurate methods, such as ADP, were not available. Due to its easy access, BIA, unlike ADP, is commonly used in clinical settings, and hence it is useful to further knowledge on its use in research settings as well.

With respect to preschool children (Studies III & IV), the major strengths were the use of accurate and up-to-date methodology in measuring PA, body composition and physical fitness in both a cross-sectional and a longitudinal design. Analyzing accelerometer data using cut-points and VM percentiles as along with isotemporal substitution analyses (Study III) were all in line with each other, and hence the findings were strengthened. Furthermore, having accurate PA and SB data at both baseline and follow-up enabled examination of the relationships of the changes in PA and SB with changes in body composition and physical fitness over the 12-month follow-up (Study IV).

Studies III and IV have also some limitations that need to be discussed. The sample size used in Study IV is somewhat small since, in order to avoid biased results, the children in the intervention group were excluded. However, the study was powered to detect relatively weak associations, and despite the relatively small sample size, the associations found were strong and consistent. Studies III and IV were observational, and thus, causality cannot be determined. No cut-points for wrist-worn wGT3x-BT recordings for preschool children were available when Study III was initiated, and therefore, cut-points derived from 8-12-year-olds were used in assessing SB, LPA, MPA and VPA (Chandler et al. 2015). Cut-points for wrist-worn wGT3x-BT in preschool children have recently been published (Johansson et al. 2016); however, the cut-points only applied to SB and MVPA. Since the present aim was to compare results between the present cross-sectional and longitudinal studies, the same cut-points (i.e. for older children) were used. In the cross-sectional study, the accelerometer data were analysed using both cut-points and VM percentiles, and the results were consistent. The findings of the cross-sectional study have recently been confirmed by Collings et al. (2017). It is therefore unlikely that the cut-points for 8-12-year-olds affected the results. Unlike recommended, children with at least 3 days of valid data instead of at least 4 days (Migueles et al. 2017) were included in the analyses in Studies III and IV. However, 97.7% of the children had at least 4 days of valid data, and the rest did not significantly differ from the whole sample. Furthermore, all children and the mothers (Studies II, III & IV) had on average 6.5-6.7 valid days of accelerometer data per week, which increases the reliability of the measured PA and SB.

In Study I and in the GDM risk group in Study II, more than half of the women had a BMI above 25 kg/m^{2,} which is representative of the target group. Furthermore, in Study I, the women's mean BMI was 26.3 kg/m^2 and 41.7% were overweight or obese (BMI ≥25 kg/m^2), whereas the corresponding values in Study II were 25.7 kg/m^2 and 47.3%. In 2016, among all pregnant women in Finland, a mean BMI was 24.7 kg/m^2, of which 36% were overweight (BMI 25-29.9 kg/m^2) and 13% were obese (BMI ≥30 kg/m^2). In light of these numbers, the women in Studies I and II had only a slightly higher mean BMI compared to the pregnant women in general. Population-based recruitment from municipal maternity clinics and a high participation rate among the preliminarily eligible women (88%) (Aittasalo et al. 2012) improves the generalizability of the findings to the target group. It is possible that the women who were physically more active and also more aware of a healthier lifestyle participated in the study, especially in the follow-up, and this may have biased the results. In sum, the results can be well generalized to pregnant women at risk for GDM. Generalizing the results for the preschool children (Studies III & IV) to the general population is supported by the fact that the BMI of the participating parents was in accordance with that of the general Swedish population (Statistics Sweden 2010), and that the children's body size and prevalence of overweight were comparable to Swedish national data (Public Health Agency of Sweden 2014). The parents of the participating children were slightly better educated than the general Swedish population (Statistics Sweden 2010), which may in turn limit the generalizability of the results due to the association between high parental education and higher performance in motor testing in the preschool children (Bayer et al. 2009). However, parental level of education was taken into account in the analyses, and did not make a significant difference to the results.

The reported associations of PA with physical fitness and body composition in this dissertation, may be partly due to genetic pleiotropy. Pleiotropy indicates that a single gene influences more than one phenotypic trait at the same time, for example, easiness to exercise, high physical fitness level and favourable body composition profile (Kujala 2011). This may lead to an association of baseline PA with physical fitness and body composition. In young children, investigating the protective effect of PA and/or physical fitness against chronic disease is problematic due to the lack of very long-term randomized controlled trials as well as limitations regarding longitudinal observational studies, such as evaluation of causality and control for different confounding factors (Kujala 2011).

Since the studies included vulnerable target groups, pregnant women and children, discussion about the ethical aspects is warranted. In Studies I and II, the women provided, also on the behalf of their children, written informed consent to participate in the study, and in Studies III and IV informed consent was retrieved from both parents in accordance to the Helsinki Declaration (World Medical Association 2017). Pregnant women are a vulnerable group, since pregnancy produces many social, psychological, behavioural and biological changes (Devine, Bove & Olson 2000), which may influence women's behaviour. Children, however, are incapable of judging risks, assessing consequences, and furthermore, are influenced by others. To avoid misunderstanding, the methods used in the studies were carefully explained and demonstrated to the participants, and furthermore, as stated in the Declaration of Helsinki (World Medical Association 2017), the participants were allowed to withdraw from the studies at any time. According to the Declaration of Helsinki, including vulnerable groups in the research is only justified if the research is responsive to the health needs or priorities of the groups, the research cannot be carried out in a non-vulnerable group, and finally, the groups benefit from the results based on the research. There was no physical risk involved in the studies, and all the applied methods have been proven suitable for the target groups. It is noteworthy, that in Studies III and IV, physical fitness tests and the use of the BodPod may have been a challenge in children due to the young age and their ability to attend to the measurement protocol. The most difficult test to apply was the 20-m shuttle run test, due to the strenuous nature of the test and thus it was placed last in the test battery. Most likely therefore, the 20-m shuttle run test was the only test with slightly more missing data. Overall, most of the children followed the protocol for BodPod and the rest tests within PREFIT test battery well. The main reason for successful data collection was that all staff had previous experience in handling young children and they were all carefully trained to conduct the BodPod and physical fitness measurements for this age group. Finally, all collected information was anonymized, and could only be accessed by the research team.

This thesis included Finnish and Swedish young preschool children, and although the studies do not compare them in any way, the main outcomes, PA and body composition, merit some comments. First, PA levels in Finnish and Swedish children are very similar (Tremblay et al. 2016a), although some differences exist. Swedish children participate slightly more often in organized sport, whereas Finnish children use more active modes of transportation and are more active in school (Tremblay et al. 2016a). In promoting PA in children, it is essential to be aware of the typical PA patterns, and keep in mind the context in which PA needs more support. For instance, in Sweden, PA promotion could be targeted on increasing active transportation and PA at schools, while in Finland, the focus could be to active children more in participating organized sports.

Furthermore, of the Finnish 5-year-old boys 11.2% have been reported to be overweight/obese and 22.7% of the girls, while the corresponding rates at the age of 7 are 21.6% in boys and 22.1% in girls (Kaikkonen et al. 2012). In Sweden, however, on average 10-15% of the 4-year-old children are overweight/obese, whereas in older children the prevalence is even higher (Bråbäck, Gunnel & Ekholm 2009, Stockholm County Council 2013, Uppsala-Örebro Region Care Program 2015). In this context, it is relevant to note that the two countries have a relatively similar situation what comes to the prevalence of overweight/obese young children as well as the amounts of children meeting the recommended levels for PA (Tremblay et al. 2016a). Also, maternity health care is free of charge in both countries, and it includes frequent access during and after pregnancy until the offspring is 6 years of age. Thus, it may be speculated that the results based on Studies I and II in Finland may be relevant also in Sweden, and the results regarding preschool children, based on Studies III and IV, may be relevant also in Finland as long as the target groups are equivalent.

6.7 Implications and future directions

Pregnant women at risk for GDM face numerous barriers for LTPAexHH during pregnancy. Furthermore, women at GDM risk may not be able to increase or maintain their LTPAinHH in the long term as well as women without GDM risk. The findings of this study are in line with those the previous studies; however, the results should be confirmed using objective measurements of PA, and possibly include a larger sample of women without GDM risk. As confirmed here, the beneficial effects of PA on health are clear, and thus these results may be more broadly helpful, especially in health care, kindergartens, and schools.

The results of this study highlight the need to improve the knowledge of health care professionals and keep them up to date regarding recommendations and the indicators and contraindicators for PA during pregnancy to be able to support women more effectively. Furthermore, PA counselling should, as far as possible, be a component of routine maternity clinic practice, while spouses or other close people should be activated to support PA in pregnant women. Health care professionals in particular should pay more attention in promoting PA by increasing social support.

In Study III, an increase in VPA as small amount as 5 min/day, was associated with significant positive findings in body composition and physical fitness. Similarly, in Study IV strong associations of PA with body composition and physical fitness were found over the one-year follow-up, 5 min/day greater VPA at the age of 4.5 was associated with a healthier body composition and better physical fitness one year later. Thus, it can be concluded that the associations may have relevance from a clinical point. The results cannot be used as a basis for recommendations to individual children since these studies are observational only. However, the findings indicate that the associations found may be strong enough to have some clinical significance and that they are probably strong enough to have importance for public health. The results are also very informative for researchers planning future intervention studies focusing on the potential benefits of high-intensity PA in preschool children. Interventions to increase high-intensity PA, for instance through games or structured PA that include short and high bursts of intensity, may be effective in increasing high-intensity PA, and so support healthy body composition and physical fitness.

To summarize, more research is needed to clarify the factors associated with different PA patterns among women at GDM risk as well as the long-term associations between maternal and child PA using objective measurements. Furthermore, the associations of PA with body composition and physical fitness should be confirmed over a longer follow-up period during childhood. Also, further studies examining the associations of different doses of PA in varying frequencies, intensities, and durations with body composition and physical fitness would be needed.

7 MAIN FINDINGS AND CONCLUSIONS

The main findings and conclusions of this dissertation are:

1. PA prior to pregnancy and support from close family members positively influenced LTPAexHH in pregnant women. Therefore, to maximize the positive health benefits for pregnant women and their children, physical activity promotion should be targeted to all women who are planning pregnancy already before becoming pregnant.

2. Women without GDM risk increased their level of LTPAinHH significantly more than women at GDM risk. However, maternal GDM risk did not have a long-term influence on child PA or body composition in early childhood. Moreover, BMI prior to pregnancy negatively influenced on boys' body composition. Therefore, preventing the development of GDM risk factors, especially high BMI, is essential in supporting mothers' and their children's PA and healthy body composition in both the short and long term.

3. In the cross-sectional study, high-intensity PA was associated with higher FFMI and with better physical fitness in 4-year-old children. Promoting high-intensity PA at an early age may be beneficial in preventing childhood obesity and supporting better physical fitness.

4. In the longitudinal study, high-intensity PA at the age of 4.5 was associated with higher FFMI and better physical fitness at 5.5 years of age. The results suggest that enhancing high-intensity PA at an early age may be beneficial in supporting children's healthy body composition and physical fitness in the long term.

YHTEENVETO (FINNISH SUMMARY)

Liikunta raskauden aikana ja varhaislapsuudessa raskausdiabeteksen riskin ja lasten kehon koostumuksen näkökulmasta

Liikkumattomuuden ja lihavuuden yleistymien sekä lapsilla että aikuisilla on yksi nykypäivän suurimmista haasteista. Säännöllisen liikunnan on todettu olevan yhteydessä lukuisiin terveyshyötyihin, jonka vuoksi sitä suositellaan elämänkaaren kaikissa vaiheissa. Huolimatta liikunnan positiivisista terveysvaikutuksista, merkittävä osa väestöstä ei kuitenkaan liiku suositusten mukaan. Viime vuosina tutkijoiden kasvavana mielenkiintona onkin ollut selvittää riittämättömään liikuntaan ja ylipainoon yhteydessä olevia tekijöitä, jotta terveydenedistämistyötä voidaan perustellusti toteuttaa sekä kohdentaa oikeille kohderyhmille. Raskausaikaa pidetään otollisena aikana terveiden elämäntapojen omaksumiselle lisääntyneen motivaation sekä säännöllisten neuvolakäyntien vuoksi. Tällöin olisi mahdollisuus myös tuottaa terveyshyötyjä samanaikaisesti kahdelle sukupolvelle sekä saada alkuun hyvät lähtökohdat uudelle sukupolvelle.

Säännöllisen liikunnan on todettu olevan yhteydessä muun muassa useiden pitkäaikaissairauksien ennaltaehkäisyyn sekä vähentävän ennenaikaista kuolemanriskiä. Raskausajan liikunnalla puolestaan on positiivisia terveysvaikutuksia myös syntymättömän lapsen, eli sikiön, terveyteen. Äidin liikunta raskausaikana muun muassa tukee sikiön normaalia kasvua, vähentää rasvakudoksen kasvua sekä lisää stressinsietokykyä. Liikunta lisää myös energiankulutusta, jonka vuoksi sillä saattaa olla merkittävä rooli ylipainon ehkäisyssä. Riittämätön liikunta on noussut erityiseksi huolenaiheeksi lasten kohdalla ylipainon lisääntyessä. Lasten ylipaino on yhdistetty moniin fyysisiin ja psyykkisiin terveysriskeihin, kuten lisääntyneeseen riskiin sairastua aineenvaihduntasairauksiin sekä heikentyneeseen elämänlaatuun. Ylipainon on todettu kehittyvän varhaisesta lapsuudesta nuoruusikään, joten ehkäisykeinojen kohdentaminen mahdollisimman varhaisessa elämänvaiheessa on tärkeää.

Fyysistä kuntoa puolestaan on pidetty merkittävänä terveysmittarina kouluikäisillä lapsilla ja nuorilla. Hengitys- ja verenkiertoelimistön kunnon parantuminen on ollut yhteydessä pienempään ylipainon riskiin murrosikäisenä, kun puolestaan hyvä lihasvoima on yhdistetty terveydelle suotuisaan kehon koostumukseen, parempaan psyykkiseen terveyteen sekä pienempään ennenaikaiseen kuolemanriskiin.

Raskausajan liikunnalla saattaa olla vaikutusta myös raskausajan diabeteksen ehkäisyssä. Raskausajan diabetes on komplikaatio, jossa naisen verensokeriarvoissa todetaan huomattavaa nousua ensimmäisen kerran raskauden aikana. Raskausajan diabeteksen on puolestaan todettu lisäävän sekä äitien että sikiön myöhempää riskiä sairastua moniin pitkäaikaissairauksiin kuten tyypin 2 diabetekseen. Raskausdiabeteksen riskitekijöitä on äitien korkea ikä, raskautta edeltävä ylipaino, sukurasite diabetekseen sekä sokeriaineenvaihdunnan häiriöt aiemmissa raskauksissa. Riskitekijät ovat yleistyneet maailmanlaajuisesti, jonka vuoksi on tärkeää selvittää riskitekijöiden merkitys äitien ja heidän lasten lyhyen ja pitkän aikavälin terveydelle.

Aikaisemmat tutkimukset raskausajan liikunnasta eivät ole keskittyneet raskausdiabeteksen riskissä oleviin naisiin vaan yleisemmin joko koko väestöön tai jo raskausdiabetekseen sairastuneisiin. Seurantajaksot ovat usein rajoittuneet muutamasta kuukaudesta vuoteen, joten pitkän aikavälin seurantatieto puuttuu. Myöskään äitien raskausdiabeteksen riskin vaikutusta lapsiin ei ole aikaisemmin tutkittu. Aikaisempia tutkimuksia varhaislapsuuden liikunnan yhteyksiä kehon koostumukseen tai fyysiseen kuntoon on toistaiseksi vielä hyvin vähän.

Tämän väitöskirjatutkimuksen tarkoituksena oli selvittää raskausdiabeteksen riskissä olevien naisten liikuntaan vaikuttavia tekijöitä, sekä raskausdiabeteksen riskin yhteyttä äitien ja lasten liikuntaan sekä lasten kehon koostumukseen seitsemän vuoden seurannan jälkeen. Lisäksi tutkittiin alle kouluikäisten lasten liikunnan yhteyttä kehon koostumukseen ja fyysiseen kuntoon. Tutkimuksessa hyödynnettiin sekä poikkileikkaus- että pitkittäisasetelmaa.

Tutkimuksessa käytettiin useita eri aineistoa. Itseraportoidun ja objektiivisesti mitatun liikunnan tarkasteluissa hyödynnettiin satunnaistetun ja kontrolloidun NELLI-interventiotutkimuksen ja NELLIn 7-vuotisseurantatutkimuksen aineistoja, joihin kuului raskausdiabeteksen riskissä olevia äitejä ja heidän lapsistaan. Äidit jaettiin kahteen ryhmään sen mukaan, oliko heillä alkuraskaudessa raskausdiabeteksen riskitekijöitä vai ei. Lisäksi käytettiin kyselylomakkeita ja äitiyskortteja liikuntaan vaikuttavien asioiden selvittämisessä. Lasten liikuntaa mitattiin lisäksi objektiivisin menetelmin sekä kehon koostumusta sähköisellä bioimbedanssimenetelmällä. Alle kouluikäisten lasten liikunnan sekä kehon koostumuksen ja fyysisen kunnon välisiä yhteyksiä tarkasteltiin sekä poikkileikkaus- että pitkittäisasetelmassa perustuen satunnaistettuun ja kontrolloituun MINISTOP- interventiotutkimuksen aineistoon. Liikuntaa mitattiin objektiivisesti kiihtyvyysanturilla, kehon koostumusta PodBod-menetelmällä ja fyysistä kuntoa PREFIT-testipatteristoon kuuluvalla neljällä testillä (hengitys- ja verenkiertoelimistön kunto, ylä- ja alaraajojen lihasvoima sekä motorinen kunto).

Tulosten mukaan raskausdiabeteksen riskissä olevien naisten vapaa-ajan liikunta väheni raskauden aikana sekä muuttui intensiteetiltään kevyemmäksi. Vapaa-ajan liikuntaan vaikuttivat positiivisesti sekä naisten oma- että puolison liikunta-aktiivisuus ennen raskautta sekä naisten osa-aikatyö. Kannustaviksi henkilöiksi naiset kokivat läheiset ihmiset kuten puolison ja ystävät. Lähes 80% naisista koki, että kukaan ei rajoittanut heidän vapaa-ajan liikuntaa, sen sijaan rajoittaviksi tekijöiksi he raportoivat väsymyksen, huonon olon ja ajanpuutteen. Kun tarkasteltiin liikunnan muutosta raskautta edeltävän ajan ja seitsemän vuoden seurannan välillä, havaittiin, että naiset, joilla ei ollut raskausdiabeteksen riskiä alkuraskaudessa lisäsivät liikuntaa merkitsevästi enemmän kuin raskausdiabeteksen riskissä olevat naiset (vähintään yksi raskausdiabeteksen riskitekijä alkuraskaudessa). Toisaalta, lasten kehon koostumuksessa tai liikunnan määrässä 6,5-vuotiaana ei ollut eroja sen mukaan oliko äidillä raskausdiabeteksen riskiä vai ei. Sen sijaan yksittäisistä riskitekijöistä, äidin korkeampi raskautta edeltävä painoindeksi (kg/m^2) oli yhteydessä pojan epäsuotuisaan kehon koostumukseen. Tarkasteltaessa äitien ja lasten liikunnan välisiä yhteyksiä poikkileikkausasetelmassa seitsemän vuotta synnytyksen jälkeen, äitien liikkumattomuus oli positiivisesti yhteydessä lasten liikkumattomuuteen sekä negatiivisesti vähintään kohtuutehoiseen liikuntaan. Lisäksi äitien vähintään kohtuutehoinen liikunta oli negatiivisesti yhteydessä lasten liikkumattomuuteen ja positiivisesti vähintään kohtuutehoiseen liikuntaan. Alle kouluikäisillä lapsilla puolestaan todettiin korkeatehoisen liikunnan olevan merkitsevästi yhteydessä suotuisaan kehon koostumukseen ja parempaan fyysiseen kuntoon sekä poikkileikkaus- että pitkittäisasetelmassa.

Yhteenvetona voidaan todeta, että raskausdiabeteksen riskissä olevilla naisilla raskausajan vapaa-ajan liikunnan jatkumisen kannalta tärkeässä roolissa ovat raskautta edeltävä liikunta-aktiivisuus ja läheisten ihmisten tuki. Toisaalta raskausdiabeteksen riskitekijöiden, erityisesti ylipainon, ehkäisyyn tulisi kiinnittää huomiota jo raskautta suunniteltaessa, jotta äitien liikuntaa sekä lasten terveyttä tukevaa kehon koostumusta ja liikuntaa voitaisiin edistää pitkällä aikavälillä. Korkeatehoinen liikunta alle kouluikäisillä lapsilla puolestaan vaikuttaa olevan merkittävää lasten ylipainon ehkäisemisessä ja fyysisen kunnon edistämisessä.

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ORIGINAL PUBLICATIONS

I

PHYSICAL ACTIVITY DURING PREGNANCY: PREDICTORS OF CHANGE, PERCEIVED SUPPORT AND BARRIERS AMONG WOMEN AT INCREASED RISK OF GESTATIONAL DIABETES

by

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Physical Activity During Pregnancy: Predictors of Change, Perceived Support and Barriers Among Women at Increased Risk of Gestational Diabetes

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Abstract The aim of this study was to examine the predictors of change in intensity-specific leisure-time physical activity (LTPA) during pregnancy, and the perceived support and barriers of LTPA in Finnish pregnant women at increased risk of gestational diabetes. The study population consisted of 399 pregnant women who participated in a randomized controlled trial aiming to prevent gestational diabetes. Evaluation of LTPA was based on a self-report at baseline, 26–28, and 36–37 weeks' gestation. Data on predictors of change, perceived support and barriers were collected with questionnaires and from the maternity cards. Multinomial logistic regression was used to assess associations between the variables. The average weekly minutes of light-intensity LTPA were 179 at baseline, 161 at 26–28 weeks' gestation, and 179 at 36–37 weeks' gestation. The corresponding minutes of moderate-to-vigorous-intensity LTPA were 187, 133 and 99. At 26–28 weeks' gestation, the strongest predictors for light-intensity LTPA were meeting the PA recommendations prior to pregnancy, having polytechnic education and working part-time, while having a physically active spouse prior to pregnancy was the strongest predictor for moderate-to-vigorous-intensity LTPA. The people and/or factors that encouraged women to LTPA the most were the spouse, a child, other family members and weather, whereas tiredness, nausea, perceived health, work and lack of time restricted their LTPA the most. The strongest predictors for maintaining LTPA during pregnancy were pre-pregnancy LTPA, education, working part-time and a spouse's LTPA. Most common barriers were perceived health, work and lack of time.

Keywords Physical activity · Pregnancy · Predictors · Perceived support and barriers · Gestational diabetes

Introduction

Regular physical activity during pregnancy is associated with marked benefits for both mother and fetus. For mothers physical activity improves cardiovascular function, helps to limit pregnancy weight gain, and decrease musculoskeletal problems and gestational hypertension, while fetal benefits include decreased fat mass and improved stress tolerance [1]. On the other hand, moderate-intensity physical activity during pregnancy does not seem to impact negatively on pregnancy outcomes, such as preterm birth [2–4]. Exercise guidelines recommend at

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least 150 min of moderate-intensity aerobic exercise a week for all healthy women during pregnancy [5]. However, pregnant women are not generally so active physically [6, 7], and for example only about 15 % of Norwegian women meet this recommendation [8].

Leisure time physical activity (LTPA) before and/or during pregnancy may have a protective effect also on the development of gestational diabetes mellitus (GDM) [2, 9]. GDM is a serious complication of pregnancy associated with increased risk of adverse outcomes for both the mother [10] and the fetus [11] during pregnancy and in later life. Also the risk of developing type 2 diabetes has increased among women with GDM [11]. The prevalence of GDM is increasing worldwide [9], and in Finland 12.5 % of women was diagnosed with GDM in 2011 [12]. In this light, pregnancy is an essential time for LTPA promotion, in order to enhance the immediate and longer-term health benefits for the mother and the fetus [1, 2, 9].

However, LTPA frequency, duration and intensity tend to decline during pregnancy [2, 13–17]. The most commonly reported exercise modes are walking, swimming and other low-intensity activities [7, 15, 18]. To promote physical activity more effectively in maternity care health care professionals need more profound information about pregnancy-related predictors and determinants of physical activity. According to earlier studies the predictors of low physical activity during pregnancy include having other children at home, lower education [14], being less physically active prior to pregnancy [7, 14, 19], having pelvic girdle pain and nausea or being overweight prior to pregnancy [7]. At the same time, a spouse and other family members seem to have strong positive association with physical activity during pregnancy [20].

Theoretical models most commonly applied in the studies examining the determinants of physical activity behavior among pregnant women are the theory of planned behavior [21–24], protection motivation theory [25], and social cognitive theory [26]. Based on these studies it seems that normative beliefs (influences) and control beliefs (obstructive factors) play an important role in explaining pregnant women's physical activity. Self-efficacy has been reported to have a major role in overcoming barriers and maintaining LTPA during pregnancy [26].

To date, little is known about the predictors and determinants of LTPA during pregnancy among women at increased risk of GDM. Therefore, the aim of this study was to examine the predictors of intensity-specific LTPA and the perceived support and barriers for LTPA among Finnish pregnant women at increased risk of GDM. Our hypothesis is that pre-pregnancy body mass index (BMI), meeting physical activity recommendation prior to pregnancy, having other children at home and spouse's physical activity level are predictors for LTPA during pregnancy among women at increased risk for GDM. We also hypothesize that a spouse and other family members are perceived supporters for LTPA whereas health related issues are perceived barriers for LTPA during pregnancy.

This study is based on a data from a cluster-randomized controlled trial aiming to prevent GDM [27]. The effects of the intervention on gestational diabetes [28] and on physical activity [29] have been reported elsewhere.

Methods

Participants

The design and methods of the study have been described in detail previously by Luoto et al. [27]. The study was conducted in maternity clinics of primary health care centers in 14 municipalities in Pirkanmaa region in south-western Finland. Fifty-three nurses working in the maternity clinics in these municipalities recruited pregnant women at increased risk of GDM at 8–12 week gestation. The risk of GDM was screened by using the following risk factors (2010): BMI $\geq$25 kg/m^2 based on measured height and self-reported pre-pregnancy weight; GDM or any signs of glucose intolerance or newborn's macrosomia ($\geq$4.500 g) in any earlier pregnancy, family history of diabetes, or age $\geq$40 years. Pregnant women with at least one GDM risk factor, were permitted to enter the study. Women were excluded if they had any of the following criteria: gestational or type 1 or type 2 diabetes; inability to speak Finnish; age <18 years; multiple pregnancy; physical restriction preventing physical activity; substance abuse; treatment or clinical history for psychiatric illness. The recruitment period lasted from 1 October 2007 to 31 December 2008, and the study was completed when all women had given birth at the end of September in 2009. All participants provided written informed consent to participate in the study, which was conducted according to ethical principles of The Finnish National Advisory Board on Research Ethics (http://www.tenk.fi/sites/tenk.fi/files/ethicalprinciples.pdf) and was approved by the Ethical Committee of Pirkanmaa Hospital District.

The study population consisted of 399 pregnant women at increased risk of GDM. The women were randomized to intervention (INT) and usual care (UC) groups. 45.1 % of the whole study group participated in UC and 54.9 % in INT. INT included intensified physical activity and dietary counseling, which were, respectively, integrated into 5 and 4 routine maternity care visits by a public health nurse. During the counseling the participant was assisted to make a weekly action plan, which was to be followed until the next visit. The INT and the UC groups were merged for the analyses of the present study.

Predictors of Change for LTPA

The questions concerning the measurement of LTPA are described in Table 1. Evaluation of LTPA was based on a validated self-report at baseline (8–12 weeks' gestation), 26–28 and 36–37 weeks' gestation [30]. At baseline the questions concerned pre-pregnant LTPA during the 1 month before pregnancy and at follow-ups LTPA during the past 1 month. The questionnaire was divided into two parts: (1) LTPA excluding household activities and gardening and (2) household activities and gardening only. This study focuses only on the first one because it is more relevant in the light of PA promotion. The assessment of the LTPA intensity was helped by describing the degree of shortness of breath and by giving plenty of examples of different kinds of physical activities and their intensities (Table 1). The weekly minutes of intensity-specific LTPA were calculated by multiplying the number of days and the average minutes of daily LTPA. The intensity levels were categorized as light-intensity LTPA, moderate-intensity LTPA and vigorous-intensity LTPA. In the analysis the categories "moderate" and "vigorous" were combined as "moderate-to-vigorous-intensity".

Table 1 The baseline (8–12 weeks' gestation) questions on leisure-time physical activity (LTPA) and on factors encouraging and restricting LTPA

Leisure-time physical activity (LTPA) excluding household activities and gardening
Think about your normal week before pregnancy. Take into account all regular at least 10-minute LTPA sessions which were not related to household activities or gardening
(a) On how many days were you physically active so that you did not get much out of breath (e.g. "Sunday or city walking", light outdoor exercise with the children, peaceful home exercise, slow swimming)? (b) On average how many minutes per day did you spend on this kind of activity? (c) What was your primary mode physical activity? (Light-intensity LTPA)
(a) On how many days were you physically active so that you got *somewhat* out of breath (e.g. walking, jogging with the children, cycling (speed under 20 km/h, gym-exercise, group exercise, dancing, water exercise)? (b) On average how many minutes per day did you spend on this kind of activity? (c) What was your primary mode physical activity? (Moderate-intensity LTPA)
(a) On how many days were you physically active so that you got *strongly* out of breath (e.g. jogging, aerobic (running, jumps), step-aerobic, floor ball, cycling (speed at least 20 km/h), travel swimming, water running, Nordic walking (speed at least 6 km/h)? (b) On average how many minutes per day did you spend on this kind of activity? (c) What was your primary mode physical activity? (Vigorous-intensity LTPA)
Factors and persons encouraging and restricting LTPA
Think about the normal week before pregnancy. Take into account all regular at least 10-min LTPA sessions
(a) What affected your LTPA the most and in what way? List the factors, which affected the most and indicate by circling whether it encouraged or restricted your LTPA. The participants had also an option to mark an X to "nothing affected my LTPA."
(a) Who affected your LTPA the most and in what way? List persons or groups, which affected the most and indicate by circling whether they encouraged or restricted your LTPA. The participants had also an option to mark an X to "no-one affected my LTPA."

The data on the potential predictors for LTPA change from pre-pregnant level to 26–28 weeks' gestation were obtained from the standard maternity card: age, pre-pregnancy BMI, primiparity; and from the baseline questionnaire: education, working fulltime, having other children under 7 years, previous miscarriages, meeting PA recommendations and spouse's physical activity prior to pregnancy. The latter was proxy-reported by the pregnant mother on a 6-point scale: (1) almost no physical activity every week, (2) some light-intensity physical activity on at least 1 day in every week, (3) brisk physical activity approximately once a week, (4) brisk physical activity approximately twice a week, (5) brisk physical activity at least three times a week, (6) I'm not aware of my spouse's physical activity habits. In the analysis categories 1–3 indicated "inactive" and categories 4–5 "active".

Perceived Support and Barriers

The factors and persons that encouraged and restricted participants' LTPA at 26–28 weeks' gestation were asked by open-ended questions (Table 1) contrary to earlier studies, which have mostly given ready-made alternatives [31–33]. Open-ended questions were used to better enable women's own expressions and to get a more complete picture about the restrictive and encouraging factors. The participants were permitted to list as many matters as they wanted but only the first three to both categories (factors, persons) were taken into account.

Statistical Methods

Descriptive information is given as arithmetic means and standard deviations (SD) or frequencies and percentages. Multinomial logistic regression was used to assess the association between the potential predictors and the outcome variables, the changes in the weekly minutes of light-intensity or moderate-to-vigorous-intensity LTPA each classified into three categories: (1) the weekly minutes of LTPA decreased more than 30 min, (2) the weekly minutes of LTPA were maintained (i.e. decreased <30 min or increased no more than 30 min, and (3) the weekly minutes of LTPA increased more than 30 min. The 30 min cut-off points were chosen because the recommendation for pregnant women suggests at least 30 min moderate-to-vigorous-intensity physical activity on 5 days a week [5].

As LTPA usually decreases during pregnancy [2, 13–17] odds ratios (ORs) and 95 % confidence intervals (95 % CIs) were calculated using the first category as the baseline category. The predictors used in the models were age (≥30/<30), BMI prior to pregnancy (<25/≥25 kg/m^2), education (academic/polytechnic/basic or secondary school), fulltime working (no/yes), other children under 7 years (no/yes), miscarriages in earlier pregnancies (no/yes), meeting PA recommendations prior to pregnancy (no/yes), physically active spouse prior to pregnancy (no/yes). Each model was adjusted for baseline value of each specific PA outcome in weekly minutes.

Since part of the pregnant women received physical activity counseling, the potential differences between the INT and UC groups in perceived support and barriers were analyzed by using multilevel logistic regression model. The group variable (INT/UC) was used as explanatory variable, while marital status and previous childbirths were used as adjusted variables.

Multinomial logistic regression was also used to assess the association between the perceived support and barriers and the changes in the weekly minutes of light-intensity or moderate-to-vigorous-intensity LTPA in each of their three categories. ORs and 95 % CIs were calculated using the first category—the weekly minutes of LTPA decreased more than 30 min—as the baseline category. Data were analyzed using the statistical software package STATA Release 12 (College Station, Texas: StataCorp LP).

Results

Baseline characteristics of the participants are presented in Table 2. On average, the women were 30 years old and had BMI of 26. More than half of the participants had previous childbirth, polytechnic education or above, were working fulltime, had other children under 7 years, were married or in cohabitation and had a physically active spouse.

Physical Activity During Pregnancy

When analyzing changes in the intensity-specific LTPA only the women who had data on all of the three evaluation points were included. The complete data on light-intensity LTPA was available for 339 (85 % of 399) women and data on moderate-to-vigorous-intensity LTPA for 335 (84 % of 399) women.

The weekly minutes of light-intensity LTPA were 179 (SD 226) at baseline, 161 (SD 197) at 26–28 weeks' gestation, and 179 (SD 197) at 36–37 weeks' gestation on average. The most commonly reported mode of light-intensity LTPA was walking throughout the pregnancy.

Table 2 Baseline characteristics of the participants (N = 399)

Age in years, mean (SD)	29.7 (4.7)
≥30 [N (%)]	199 (49.9)
<30 [N (%)]	200 (50.1)
Primiparous [N (%)]	176 (44.1)
Body mass index (BMI, kg/m^2) before pregnancy, mean (SD)[a]	26.3 (4.7)
≥25 [N (%)]	166 (41.7)
<25 [N (%)]	232 (58.3)
Education [N (%)]	
Academic	94 (24.0)
Polytechnic	165 (42.2)
Basic or secondary school	132 (33.8)
Working fulltime [N (%)]	251 (62.9)
Other children under 7 years [N (%)]	205 (51.5)
Miscarriages in earlier pregnancies [N (%)]	92 (23.2)
Meeting physical activity recommendations prior to pregnancy [N (%)][b]	200 (52.0)
Marital status [N (%)]	
Married or in cohabitation	382 (95.7)
Single	15 (3.8)
Judicial separation or divorced	2 (0.5)
Physically active spouse prior to pregnancy [N (%)][c]	216 (55.0)
Leisure-time physical activity (minutes/week), mean (SD)	
Light-intensity	179 (226)
Moderate-to-vigorous-intensity	187 (177)

[a] Based on self-reported pre-pregnancy weight and measured height, recorded in the standard maternity card at the first visit (8–12 weeks' gestation)

[b] The minimum of 150 min of moderate-to-vigorous-intensity LTPA spread throughout at least 3 days a week

[c] Physical activity level 4–5

The weekly minutes of moderate-intensity LTPA were 130 (SD 139) at baseline, 109 (SD 106) at 26–28 weeks' gestation, and 92 (SD 120) at 37–38 weeks' gestation on average. Walking was clearly the most popular mode of moderate-intensity LTPA during the pregnancy. Complete data on moderate-intensity LTPA was available for 338 (85 % of 399).

The weekly minutes of vigorous-intensity LTPA were 60 (SD 80) at baseline, 24 (SD 56) at 26–28 weeks' gestation, and 8 (SD 32) at 37–38 weeks' gestation on average. In vigorous-intensity LTPA the most popular modes of LTPA were walking, group exercise, jogging and cycling at baseline, and cycling and group exercise at follow-ups. Complete data on vigorous-intensity LTPA was available for 338 (85 % of 399).

The weekly minutes of moderate-to-vigorous-intensity LTPA together were 187 (SD 177) at baseline, 133 (SD 124) at 26–28 weeks' gestation, and 99 (SD 126) at 37–38 weeks' gestation on average.

Table 3 Multinomial logistic regression odds ratios (ORs) of the connected factors for changes in leisure-time physical activity weekly minutes from baseline to 26–28 weeks' gestation. PA decreased >30 min is baseline category for outcome

	N	Light-intensity PA				N	Moderate-to-vigorous-intensity PA			
		PA maintained (maximum change ± 30 min)		PA increased >30 min			PA maintained (maximum change ± 30 min)		PA increased >30 min	
		OR (95 % CI)	*p*	OR (95 % CI)	*p*		OR (95 % CI)	*p*	OR (95 % CI)	*p*
Age ≥ 30 vs <30 years	339	0.80 (0.44–1.44)	0.45	0.97 (0.53–1.75)	0.91	335	1.17 (0.67–2.04)	0.57	1.08 (0.59–1.97)	0.80
Body mass index ≥ 25 vs <25	339	0.88 (0.48–1.60)	0.67	0.86 (0.47–1.58)	0.63	334	0.96 (0.55–1.69)	0.89	1.08 (0.58–1.99)	0.82
Education (reference = basic)	336					333				
Polytechnic		1.89 (0.95–3.77)	0.071	1.49 (0.76–2.93)	0.25		0.90 (0.47–1.73)	0.76	0.89 (0.45–1.77)	0.74
Academic		1.61 (0.73–3.59)	0.24	1.10 (0.49–2.44)	0.82		0.95 (0.45–1.98)	0.89	0.63 (0.27–1.43)	0.27
Working fulltime	339	0.66 (0.34–1.27)	0.21	0.53 (0.27–1.02)	0.059	335	1.17 (0.65–2.08)	0.61	0.97 (0.52–1.81)	0.93
Other children under 7 years	338	1.13 (0.59–2.14)	0.71	1.74 (0.91–3.31)	0.094	335	0.89 (0.51–1.55)	0.68	0.69 (0.38–1.27)	0.24
Miscarriages in earlier pregnancies	338	0.84 (0.42–1.68)	0.62	0.93 (0.47–1.86)	0.85	333	0.62 (0.31–1.23)	0.17	0.98 (0.49–1.95)	0.95
Meeting PA recommendations prior to pregnancy	330	1.74 (0.94–3.24)	0.078	2.53 (1.35–4.72)	0.004	335	0.36 (0.16–0.81)	0.014	0.67 (0.25–1.76)	0.41
Physically active spouse prior to pregnancy	335	1.00 (0.55–1.83)	0.99	0.92 (0.50–1.68)	0.79	331	1.81 (1.00–3.26)	0.048	0.86 (0.47–1.60)	0.64

Each characteristic is adjusted for the baseline value of each specific PA outcome in weekly minutes

Predictors of Change

Table 3 presents the ORs for changes in LTPA in categories of various background characteristics. Regarding light-intensity LTPA the women with polytechnic education tended to be more likely to maintain their LTPA instead to decrease it comparing to women with basic or secondary school education (OR 1.89, 95 % CI 0.95–3.77). Difference between academically and basic or secondary school educated women were not discovered. The women who met the PA recommendations prior to pregnancy had clearly higher probability for increasing rather than decreasing LTPA more than 30 min compared with the women who did not meet the recommendations (OR 2.53, 95 % CI 1.35–4.72). Also the women who were working part-time had higher probability to increase rather than decrease LTPA more than 30 min compared with women who were working fulltime (OR 1.89, 95 % CI 0.98–3.70).

Regarding moderate-to-vigorous-intensity LTPA the women who met the PA recommendations prior to pregnancy had a lower probability to maintain rather than decrease their LTPA more than 30 min compared with women who did not meet the PA recommendations at baseline (OR 0.36, 95 % CI 0.16–0.81). On the other hand, the women who had a physically active spouse prior to pregnancy had a higher probability to maintain rather than decrease their LTPA more than 30 min compared with the women who had a physically inactive spouse (OR 1.81, 95 % CI 1.00–3.26).

Statistically significant differences between the INT and UC were not discovered in the predictors of change for light- or moderate-to-vigorous-intensity LTPA. Regarding the predictors, all the confounding factors were also tested together, but it did not change the results.

Perceived Support and Barriers

The factors and the persons that affected participants' LTPA at 26–28 weeks' gestation are shown in Table 4. One-third of the women indicated support from their spouse. Also friends, an exercise group and a child encouraged them to LTPA. Weather related issues, good company and having a dog were reported as encouraging factors. However, more than one-fourth of the women reported that no-one encouraged them to LTPA, and one-third of the women reported that nothing encouraged them to LTPA.

In UC a child was more often reported as a supportive person than in INT (OR 0.49, $p = 0.005$).

Table 4 The people and factors encouraging and restricting leisure-time physical activity at 26–28 weeks' gestation

	N	%
Encourage		
People		
No one encouraged	107	27.1
A spouse	131	33.2
Friends, close people, a fitness group	74	18.7
A child	69	17.5
Other (e.g. a dog)	9	2.3
Colleagues, work community	3	0.8
A coach, a fitness instructor	2	0.5
Factors		
Nothing encouraged	127	32.2
A good weather, fresh air, being outdoor, good exercise facilities	68	17.2
A dog	53	13.4
Good company, doing together, instructed group, close people	44	11.1
Physical fitness, health related issues	31	7.9
Other (e.g. renovation, unstructured physical activity)	30	7.6
A good feeling, vigor, refreshing mind, relaxation	22	5.6
Weight management	12	3.0
Sport events	8	2.0
Restrict		
People		
No one restricted	310	78.5
A child	57	14.4
A spouse	12	3.0
Friends, other close people	12	3.0
Other (e.g. colleagues)	4	1.1
Factors		
Nothing restricted	65	16.5
Tiredness, nausea and health related issues	171	43.3
A work, lack of time	105	26.6
A bad weather, long distances	38	9.6
Lack of babysitter	11	2.8
Other (e.g. lack of equipments)	5	1.3

In INT weather related issues were reported more often as encouraging factors than in UC (OR 1.96, $p = 0.009$). No other differences in the supportive factors or persons were discovered between the groups.

The most commonly reported factors restricting LTPA were tiredness, nausea and health related issues. Also a lack of time, a work or a child restricted their LTPA. However, almost eight of ten reported that no-one restricted their LTPA and one-fifth of the women reported that nothing restricted their LTPA.

In INT the lack of time and work were reported as restricting factors more often than in UC (OR 1.65, $p = 0.021$). Regarding other barriers differences between INT and UC were not discovered.

The women who reported that good company, being active together, exercise group or close people encouraged them to LTPA had a higher probability to maintain and to increase their light-intensity LTPA minutes instead of decreasing them more than 30 min compared to women who didn't report these matters as encouraging factors (OR 3.5, 95 % CI 1.26–9.78 and OR 3.0, 95 % CI 1.07–8.45, respectively).

The women who reported that tiredness, nausea and health related issues restricted their LTPA had a lower probability to increase than decrease their moderate-to-vigorous-intensity LTPA more than 30 min compared to women who didn't report same restrictions (OR 0.5, 95 % CI 0.27–0.93). In addition, the women who reported work or lack of time as restrictive matters had a higher probability to increase than decrease their moderate-to-vigorous-intensity LTPA more than 30 min compared to women who didn't report similar restrictions (OR 1.9, 95 % CI 1.00–3.57).

Discussion

LTPA decreased during pregnancy and shifted from moderate-to-vigorous-intensity to light-intensity among Finnish women at increased risk of GDM. The strongest predictors to maintain or increase light-intensity LTPA at 26–28 weeks' gestation were meeting the PA recommendations prior to pregnancy, having polytechnic education and working part-time. For moderate-to-vigorous-intensity LTPA the strongest predictor was having a physically active spouse prior to pregnancy. At 26–28 weeks' gestation a spouse, a child, family members and weather related issues encouraged LTPA the most whereas tiredness, nausea, health-related issues, work and lack of time were reported as the most common barriers.

Among women at increased risk of GDM, the trend in changes in the minutes of LTPA during pregnancy is in line with the previously published studies [2, 13–17]. The most popular mode of LTPA throughout the pregnancy was walking as in the previous studies [13, 15, 34] but also cycling and group exercise were popular in this specific study group. The results of the present study show that the changes in LTPA during pregnancy are similar, whether the women have increased risk for GDM or not. Since LTPA decrease from baseline to 26–28 weeks' gestation physical activity promotion during the second trimester would be justified in this specific target group. The intensities of the most popular modes of LTPA are easily modifiable and may therefore be favorable with pregnant women. Aittasalo et al. [29] have reported earlier that difference in the change of LTPA duration between INT and UC were not discovered. However, the intervention was able to reduce the decrease in the weekly frequency of total and moderate-to-vigorous-intensity LTPA from baseline to the end of second trimester.

The women who reported meeting the PA recommendations prior to pregnancy were also more likely to continue their light-intensity LTPA from baseline to 26–28 weeks' gestation. The positive impact of pre-pregnancy exercise has been noticed also in other studies [7, 19, 34, 35]. These results indicate that promoting a physically active lifestyle among young women prior to pregnancy is important also from this point of view. However, in moderate-to-vigorous-intensity LTPA the results indicate that physically active women prior to pregnancy were more likely to decrease their LTPA comparing to women who did not meet the PA recommendations. This finding may have resulted from the more active women replacing moderate-to-vigorous-intensity LTPA with light-intensity LTPA.

The women who were working part-time were more likely to maintain their light-intensity LTPA. This finding may be explained by the fact that they have more time and/or energy to be physically active. Juhl et al. [18] have reported earlier that women who are students or out of work are more physically active than women who are working. In this light, part-time work or flexible working hours could be a good option for pregnant women to maintain their LTPA.

Evenson and Bradley [36], Fell et al. [17] and Ning et al. [34] have reported positive association between higher education level and LTPA among pregnant women. Also the results of our study show, that polytechnic educated woman were more likely to maintain light-intensity LTPA than the women with lower education level. The women with a higher education may be more aware of healthy lifestyles and they can better maintain their LTPA also during pregnancy.

Having a physically active spouse prior to pregnancy was associated with maintaining of moderate-to-vigorous-intensity LTPA. Additionally, almost half of the women cited a spouse as a supporter to LTPA, and one-third of the women cited the spouse as a primary support to LTPA during pregnancy. The important role of a spouse in the pregnant women's LTPA has also been reported by Symons Downs and Hausenblas [20] and Weir et al. [31]. However, based on the previous studies and on our current study it remains unknown whether the physically active spouses encouraged pregnant women to be physically active or whether the finding is due to selection that physically active spouses have physically more active women as partners. Nevertheless, it seems that spouses may have important influence also on physical activity of pregnant women who are at risk of GDM. Health professionals should be aware of this fact and further encourage spouses' participation in maternity care visits to improve the continuity of physical activity counseling.

Normal weight prior to pregnancy [7] and not having other children at home [16] have reported to be associated with greater LTPA during pregnancy, while the association between LTPA and maternal age has been equivocal [14]. However, in this present study significance association between any of these predictors and intensity-specific LTPA were not discovered. To women with previous children, it may be important to provide child care and to encourage exercise together with the children.

The most interesting finding concerning *perceived support and barriers* was that only 13 out of 399 of the pregnant women reported that health professionals encouraged them to LTPA. All 13 women belonged to INT, in which everyone participated in physical activity counseling provided by maternity care nurses. In UC usual practices were followed but they also included discussions about physical activity [37]. In this light the finding is surprising but may reflect the limited time the nurses had for each individual pregnant woman to discuss about physical activity. It may also be that the pregnant women thought they were to point out persons from outside maternity care since the questionnaire was so closely related to the intervention. In addition more than one of fourth of all women reported that no-one encouraged them to LTPA. It is unclear if this finding is because they did not get any encouragement or because they didn't feel a need for encouragement. With the closed-ended questions the results may be different.

Evenson et al. [38] and Cramp and Bray [26] have also used open-ended questions to examine the barriers to LTPA and the primary findings were tiredness and lack of time. Also Symons Downs and Hausenblas [20] have reported tiredness, fatigue and time limits as barriers to LTPA but, physical limitations and restrictions (e.g. nausea) were reported as primary barriers (control beliefs). These reported barriers are in line with our findings among women at risk of GDM as almost half of them reported that health related issues, nausea and tiredness restricted their LTPA at 26–28 weeks' gestation. We also found that the women who reported health related issues, nausea or tiredness as restrictive factors had a lower probability to increase their moderate-to-vigorous LTPA compared to the women who did not report such restrictions. It is logical that health related issues, nausea and tiredness lead to a reduction of high intensity LTPA. Also lack of time and work related issues restricted every fourth women's LTPA in our study.

In UC a child encouraged more commonly to LTPA than in INT. This finding may be explained by the fact that in UC the women had more previous childbirths. In INT the weather related things were more commonly reported as encouragement factor. This finding may be a positive consequence from the intervention, in which the weekly program of LTPA was planned and followed. Also, a lack of time and a work were more commonly reported factors to restrict LTPA in INT than in UC. Concerning the other predictors significant differences between the two groups were not discovered.

Strengths and Limitations

The most important strength of the study was the large number of the pregnant women in this specific target group. Getting more information about the LTPA in this risk group can help the health professionals to optimize physical activity promotion before and during pregnancy. Knowing the factors and the people that encourage or restrict their physical activity during pregnancy guide the health professionals to focus better on these matters. The second strength of the study was that the factors associated with LTPA at 26–28 weeks' gestation were asked with the open-ended questions, which may not guide the participants' responses as much as the ready-made response alternatives. The women were thus more free for spontaneous expressions, which may have given a larger picture of the perceived support and barriers related to their physical activity.

The representativeness of the study sample may have been impaired since more than half of the women were under 30 years and were physically active prior to pregnancy. On the other hand, more than half of the women's BMI exceeded 25 which represent well the target group. The results of the study can be generalized to the pregnant women at increased risk of GDM.

One of the weaknesses of the present study is that it targeted only on LTPA, and therefore household chores and occupational physical activities were not analyzed. This limitation may have lead to biased results since some women may be physically active at work or have plenty of household chores but be quite physically inactive during leisure. Another weakness is that the measurement of LTPA was based only on self-report, which has been shown to be susceptible for under and over-reporting. However, the assessment of the LTPA intensity was aided by describing the degree of breathlessness and by giving examples of the different kinds of physical activities. Also, the questionnaire was the same at each measuring point leading to the occurrence of same kind of over- and under-estimation every time. In future studies, using data on total physical activity, preferably using also objective measurements in which household chores and occupational physical activities are also included could diminish these biases.

Conclusion

The strongest predictors for maintaining or increasing intensity-specific LTPA at 26–28 weeks' gestation were meeting the physical activity recommendations prior to pregnancy, having polytechnic education, working part-time and having a physically active spouse prior to pregnancy. People and factors, which most often encouraged LTPA were a spouse, a child, family members and weather related issues. Tiredness, nausea, health related issues, work and lack of time were the most common barriers to LTPA. Further research is needed to obtain a more reliable understanding of pregnant women's total physical activity and the factors which are associated with it. Physical activity such as household activities and occupational activities should also be included. Also using more objective measures such as accelerometers or pedometers would give more reliable information about physical activity in this specific target group.

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II

PHYSICAL ACTIVITY IN CHILDREN AND THEIR MOTHERS STRATIFIED BY GESTATIONAL DIABETES RISK: A 7-YEAR FOLLOW-UP

by

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Physical activity in children and their mothers stratified by gestational diabetes risk: a 7-year follow-up

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Running head: Exercise in mothers and their children

Abstract

Objectives: Gestational diabetes (GDM) risk factors are increasing worldwide, and there is lack of knowledge whether the presence of GDM risk is related to women's physical activity (PA) or to their children's PA and body composition.

Methods: The study included 199 Finnish women. GDM risk factors were screened in the beginning of pregnancy, and classified as absence or presence of GDM risk (i.e. at least one GDM risk factor). Using adjusted linear regression models, we examined the difference between the groups in 1) change of self-reported PA from pre-pregnancy to 7-year follow-up, 2) objectively measured PA at 7-year after delivery, 3) children's PA and body composition at the age of 6.

Results: The women without GDM risk increased self-reported light-PA on average 99 min/week and moderate-to-vigorous-PA 26 min/week from pre-pregnancy to 7-year follow-up. Among women at GDM risk, light-PA increased 29 min/week, whereas moderate-to-vigorous PA decreased 33 min/week. After adjustments, women without GDM risk had on average significantly higher change of light-PA (88 min, p=0.012) and total-PA (130 min, p=0.004) than women with GDM risk. Concerning women's objectively measured PA and children's PA and body composition at 7-year after delivery, the differences were non-significant. However, of the GDM risk factors, mothers' pre-pregnancy body mass index was positively related to unhealthier body composition in boys at 6 years of age.

Conclusions: Health promotion should be targeted to the women with GDM risk factors, in particular overweight women, in order to enhance women's PA in long-term, and their children's healthy body composition.

Introduction

Gestational diabetes (GDM) is a complication of pregnancy associated with increased risk of adverse health outcomes for the mother and fetus (American Diabetes Association 2004). The prevalence of GDM is increasing worldwide (Bardenheier et al. 2015), and in Finland 12.6% of women were diagnosed with GDM in 2016 (Vuori and Gissler 2016). Well-recognized risk factors for GDM are high maternal age, overweight, family history of type 2 diabetes and GDM or glucose intolerance in previous pregnancies (Zhang et al. 2016). In 2015, pregnant women's body mass index (BMI) was on average 24.7 kg/m^2 in Finland (Vuori and Gissler 2016). However, a long-term influence of the GDM risk factors on the mothers and/or their children has been less studied.

Regular PA is recommended at all stages of life due to its numerous health benefits (Physical Activity Guidelines Advisory Committee 2008), such as a reduced risk of GDM development during pregnancy (American College of Obstetricians and Gynecologists 2015). Sedentary behavior (SB), however, should be reduced due to its many health risks (Physical Activity Guidelines Advisory Committee 2008). The PA recommendation for all healthy pregnant and postpartum (the year following the baby's birth) has been set by the American College of Obstetricians and Gynecologists (2015). However, the women rarely meet the recommendation during pregnancy (Juhl et al. 2012) or during postpartum period (Evenson et al. 2012; van der Pligt et al. 2016). PA tends to decrease during pregnancy (Gaston and Cramp 2011; Juhl et al. 2012) and to increase again during postpartum period, although, still remaining below the pre-pregnancy level (Pereira et al. 2007; Evenson et al. 2012). Pregnancy and postpartum period are ideal times for adopting a healthy lifestyle due to increased motivation and frequent access to medical supervision (Ferrara et al. 2011). Yet, there is a lack of knowledge about the factors related to PA from pre-pregnancy over a longer period. Such information would help health care professionals offer interventions to the right target groups.

PA in early childhood (aged <7 years) has been connected to health indicators, such as lower adiposity (Butte et al. 2016; Leppänen et al. 2016), and hence, defining the factors beyond PA is needed. Maternal pre-pregnancy overweight has previously found to associate positively with childhood obesity (Catalano et al. 2009), yet due to the high prevalence of GDM risk factors among pregnant women, it is essential to investigate whether the GDM risk has an influence on children's PA and/or body composition.

Since women are sensitive for behaviour modifications during pregnancy (Ferrara et al. 2011), the “teachable moment” in promoting long-term health enhancing PA in mothers and their offspring might be beneficial to use. Thus, we sought to examine whether having GDM risk factors influences on 1) change in maternal self-reported PA from pre-pregnancy to the 7-year follow-up, 2) maternal objectively measured PA and SB at 7-year after delivery, 3) their children’s PA, SB and body composition at the age of 6.

Methods

Study design and participants

This study utilized baseline and follow-up data of the Finnish NELLI 7-year follow-up study. The baseline data is based on a cluster-randomized controlled trial aiming to prevent GDM (NELLI) (Luoto et al. 2010), and the effects of the intervention on GDM (Luoto et al. 2011) and PA (Aittasalo et al. 2012) have been previously reported. All participants provided written informed consent, and The Pirkanmaa Ethics Committee in Human Sciences has provided an ethical statement for the RCT and follow-up studies (code R14039).

Figure 1 shows the flow of participants. Pregnant women with at least one GDM risk factor, were permitted to enter the RCT study, however, the women without GDM risk factors were also allowed to respond to the PA questionnaire at baseline. The risk of GDM was screened by using the following risk factors: BMI ≥25 kg/m^2; age ≥40 years; family history of diabetes; GDM or any signs of glucose intolerance or newborn’s macrosomia (≥4,500 g) in any earlier pregnancy. The exclusion criterions have been reported elsewhere (Luoto et al. 2010).

Women were included in this study if they had responded to the PA questionnaire at baseline and at follow-up, and they as well as their children had at least 4 days of objectively measured PA at 7-year after delivery. In total, 199 dyads had all required data and they were included to the study. Of the 199 women, 56 (28.1%) were in the intervention group in the RCT study, 52 (26.1%) were in the usual care group, 32 (16.1%) were excluded from the RCT study due to GDM, and 59 (29.6%) were excluded due to the lack of GDM risk factor.

Data collection

Self-reported physical activity. PA was assessed with a validated self-report at 8-12 gestational weeks, and at follow-up 7-year after the delivery (Aittasalo et al. 2010, Leppänen et al. 2014). At 8-12 gestational weeks the questions concerned PA during a typical week prior to pregnancy, and at 7-year follow-up PA during the past one month. The intensity-specific PA levels were categorized as light-PA (LPA), moderate-PA (MPA) and vigorous-PA (VPA), and further, MPA and VPA were merged as moderate-to-vigorous PA (MVPA), and all PA intensities were calculated as total-PA (TPA).

Objectively measured physical activity. At 7-year after delivery, data on PA and SB were collected with triaxial Hookie AM20-accelerometer (Traxmeet Ltd, Espoo, Finland), which has been shown to be a valid measurement tool among adults (Vähä-Ypyä et al. 2015), adolescents (Aittasalo et al. 2015), and a feasible device among preschool children (Tuominen et al. 2016). The mothers and their children wore the waist-worn device for seven consecutive days during waking hours, except during showering and other water activities. Intensity of PA was estimated using mean amplitude deviation (MAD) of acceleration analyzed in 6s epochs (Vähä-Ypyä et al. 2015). The MAD value of each epoch was converted to metabolic equivalent (MET) value. The cut-points were defined for SB <1.5 MET, for LPA 1.5–2.9 MET, for MPA 3.0-5.9 MET and for VPA ≥6.0 MET. A valid day was defined as ≥10 hours of awake wearing time. If the daily measurement time was over 18 hours, participant was considered to have slept with the device, and the exceeding time was reduced from the SB time.

Maternal demographic characteristics. Pre-pregnancy weight and height were based on a self-report, and on measurements at the 7-year follow-up. Data on age, parity, education and working status at the first maternity clinic visit and at the 7-year follow-up were obtained from the standard maternity card and a questionnaire.

Children's anthropometry and body composition. At 7-year after delivery, height was measured using a wall stadiometer, and weight and body composition using TANITA bioelectrical impedance analysis (MC-780MA, TANITA Corporation, Tokyo, Japan). BMI was calculated as body weight (kg)/height^2 (m), and furthermore, it was modified to respond adults' BMI scale (Saari et al. 2011). Fat mass index (FMI) was calculated as fat mass (kg)/height^2 (m), and fat-free mass index (FFMI) as fat-free mass (kg)/height^2 (m). Weight-for-age and length-for-age z-scores were calculated using Finnish reference data (Saari et al. 2011).

Statistical methods

Descriptive information is given as arithmetic means (standard deviations, SD) or frequencies (percentages, %). The women were stratified in two groups by 1) absence or 2) presence of GDM risk (i.e. having at least one GDM risk factor). Linear regression analysis was used to examine the difference between the groups in 1) change in self-reported PA from pre-pregnancy to the 7-year follow-up, and 2) objectively measured PA and SB at 7-year after delivery. Each model was adjusted for age, BMI, education, working status, and number of children under 7 years in the home as well as for baseline PA (change in self-reported PA) and awake wearing time of the accelerometer (objectively measured PA). Since part of the women participated in the RCT, we investigated whether there were differences on PA outcomes by categorizing the exposure variables in four groups: 1) intervention or 2) usual care group in the RCT, 3) excluded from the RCT due to GDM, and 4) excluded from the RCT due to the lack of GDM risk factor. Since the results did not differ essentially, we decided to present the results in two groups as mentioned above.

The differences in children's PA, SB and body composition stratified by their mother's absence or presence of GDM risk, were examined using t-test (continuous variables) and Chi-square test (categorized variables). In supplementary analyses, linear regression models were used to examine the relationships between maternal pre-pregnancy BMI and children's objectively measured PA, SB and body composition at 6 years of age. Due to the significant interaction between maternal pre-pregnancy BMI and child's sex on body composition outcomes, boys and girls were examined separately. All models were adjusted for child's age, maternal education (categorized), and the models concerning PA for awake wearing time of the accelerometer.

For all analysis p-value of <0.05 was considered statistically significant. Statistical analysis was performed using SPSS Statistics 24 (IBM, Armonk, NY, USA).

Results

The demographic characteristics of the participating mothers and children, stratified according to the absence (n=47) or presence (n=152) of the mothers' GDM risk at baseline are presented in **Table 1**.

Change in self-reported PA between baseline and 7-year follow-up

At baseline (pre-pregnancy), among women without GDM risk, the weekly minutes of self-reported LPA were on average 197, MVPA 180, and TPA 377, while the corresponding minutes among women at GDM risk were on average 183, 195, and 378 (**Figure 2**). Furthermore, the weekly minutes at the 7-year follow-up were on average 296, 206, and 502 among women without GDM risk, and 212, 162, and 374 among women at GDM risk, respectively. The differences were significant between the groups regarding LPA (p=0.012) and TPA (p=0.003) at the 7-year follow-up, and borderline regarding MVPA (p=0.051). Further, the change in TPA between baseline and 7-year follow-up was significantly different (Figure 2).

The adjusted model indicates that the women without GDM risk had on average 88 min/week higher change in LPA compared to women at GDM risk (p=0.012) **(Table 2)**. In addition, the women without GDM risk had on average 130 min/week higher change in TPA compared to women at GDM risk (p=0.004). Older age and not having previous children were related to lower change in LPA and TPA over the 7-year follow-up (Table 2).

Mothers' objectively measured PA at the 7-year follow-up

The women in both groups had on average 6.7 valid measurement days (SD 0.74 and 0.56). The women without GDM risk spent on average 71% of their time in SB, 19% in LPA, and 10% in MVPA. The women at GDM risk spent 74% in SB, 17% in LPA, and 9% in MVPA, respectively. **Table 3** shows that after adjusting for confounders, the differences were non-significant. Current BMI, working status and baseline education level, however, were related to time spent in PA levels (Table 3).

Children's PA and body composition

The children of the mothers without GDM risk (n=47) had on average 6.6 valid measurement days (SD 0.68), and they spent on average 59% of their time in SB, 23% in LPA, and 18% in MVPA. The children born to mother's at GDM risk (n=152) had on average 6.5 valid days (SD 0.78), and their corresponding percentages in different PA intensities were 58, 23, and 19, respectively. The differences between the groups were non-significant.

The children of the mothers without GDM risk had on average BMI 16.0 kg/m^2, fat mass percent (%FM) 21.1, FMI 4.2, and FFMI 15.5. The corresponding means among the children born to mothers with GDM risk factors were 16.2 kg/m^2, 22.1%, 4.4, and 15.4, yet, the differences were non-significant between the groups.

Boys spent more time in MVPA compared to girls (20% vs. 18%, $p<0.001$), and furthermore, boys had lower %FM compared to girls (21.3% vs. 22.5%, $p=0.045$).

In supplementary analyses, with each additional unit of maternal pre-pregnancy BMI increased boys' BMI 0.18 kg/m^2 ($p<0.001$), %FM 0.29 ($p=0.001$), FMI 0.13 ($p<0.001$) and FFMI 0.12 ($p=0.002$) at 7-year after delivery. There were no significant relationships between any other GDM risk factors to children' PA or body composition at the age of 6.

Discussion

The women without GDM risk in the beginning of pregnancy significantly increased their self-reported LPA and TPA from pre-pregnancy to 7-year follow-up compared to the women at GDM risk. Of the GDM risk factors, pre-pregnancy BMI was positively related to boys' adiposity at 6 years of age.

Change in self-reported PA between baseline and 7-year follow-up

Despite of the amount of pre-pregnancy PA, the women without GDM risk increased their self-reported LPA and TPA over the 7-year follow-up significantly more compared to their counterparts at GDM risk. The women without GDM risk may have overall healthier lifestyle and be generally more physically active. Previously, it has been reported that the women with GDM were able to increase their self-reported PA from pre-pregnancy to one-year follow-up after the diagnosis, whereas the non-GDM group did not (Retnakaran et al. 2010). However, the findings are not comparable due to the methodological differences. Therefore, the results of this study should be confirmed using objectively measured PA and possibly, include a higher sample of women without GDM risk.

The women without GDM risk increased their self-reported MVPA more over the 7-year follow-up compared to their counterparts at GDM risk, yet, the difference was non-significant. It is possible that the number of the women without GDM risk (n=47) may be too small to indicate the statistically significant difference, and additionally, the wide range in standard deviations was likely to effect on the findings. Nevertheless, since BMI has been found to effect on the difference between absolute PA intensities and PA intensities relative to individual fitness level (Kujala et al. 2017), the finding of the present study is relevant. Overweight/obese women may have had similar reported MVPA level over the 7-year follow-up as the normal weight peers, although the absolute MVPA levels may have been different (was not measured). This point of view is essential in promoting PA among overweight/obese women, and highlights the need to relate the recommended PA to individual fitness.

Age and not having previous children were negatively related to change in self-reported LPA and TPA. The findings are somewhat expected since in our previous study (Leppänen et al. 2014), having a child was found to encourage women to PA during pregnancy. Furthermore, tiredness, nausea and poor perceived health were reported to restrict women’s PA during pregnancy. Older women may feel more tiredness and their perceived health may be weaker, which may partly explain the result in this study.

Mothers’ objectively measured PA at the 7-year follow-up

There were no significant differences between the groups. Since out of 199 women 152 (76.4%) had at least one GDM risk factor, and additionally, 51 women (33.6%) was diagnosed with GDM during pregnancy, the finding of this study is promising. The result suggests that whether the women have GDM risk in the beginning of pregnancy or they are diagnosed with GDM during pregnancy, their PA and SB may be in the same level with the counterparts without GDM risk in long-term. However, it is possible that the most inactive women declined to participate in the study, which may have biased the results.

Consistently to our findings, previous study (Herman and Saunders 2016) have reported that people with higher education are more likely to sit more due to their occupation. Since the elevated health risks related to SB are well known (Biswas et al. 2015), it is essential to pay more attention to these target groups in order to reduce the time spent in SB.

Self-reported PA investigated longitudinally changes in PA over the 7-year follow-up, while objectively measured PA examined cross-sectional relationships at 7-year after the delivery. Self-reported questionnaire assessed PA during leisure-time and household activities, whereas occupational PA was not taken into account. Objectively measured PA, however, stored all PA during the waking hours. At 7-year follow-up, self-reported TPA was significantly higher among women without GDM risk compared to their peers, but the difference was not seen in objectively measured PA at the same time point. This may partly be explained by the fact that objectively measured PA included also occupational PA and significantly more women at GDM risk were working fulltime compared to their counterparts. Although the different assessments of PA are not comparable, it is notable that some of the results are consistent. In unadjusted models, the women without GDM risk had significantly higher self-reported LPA and TPA at the 7-year follow-up compared to the women at GDM risk (Figure 2), and the similar differences were seen in objectively measured LPA and SB (reflecting contradictory TPA) (Table 3).

Children's PA and body composition

There were no significant differences in children's PA, SB or body composition stratified by their mothers' absence or presence of GDM risk. All participating mothers may have received "a natural course", indicating that all mothers were motivated to promote healthy lifestyle in their children.

We are not aware of previous studies investigating the relationships by GDM risk. A multinational cross-sectional study (Zhao et al. 2016) found a positive association between diagnosed GDM and children's obesity, but the association was not independent of maternal current BMI. Similarly, a small cohort study (n=40) (Lawlor et al. 2010) reported a positive association between diagnosed GDM and the obesity in children, but the association disappeared after adjusting for pre-pregnancy BMI. Thus, it seems that maternal pre-pregnancy and/or current BMI have a bigger role in predicting childhood obesity than diagnosed GDM or the other GDM risk factors, and that may partly explain the lack of difference between the two groups in this study.

We found a significant association between maternal pre-pregnancy BMI with all body composition measurements (BMI, %FM, FMI and FFMI) in boys. The finding is in line with the previous studies in young children (Catalano et al. 2009; Castillo et al. 2015), except the lack of significant relationships in girls. The somewhat inconsistent findings may be due to different study designs and different ethnic and genetic backgrounds. Shared genetic factors may have contributed to the association between mothers' pre-pregnancy BMI and boys' body composition. In young children, investigating the protective effect of PA or dietary habits against body composition is challenging due to the lack of long-term randomized controlled trials and methodological limitations of longitudinal observational studies (Kujala 2011). Nevertheless, it seems that pre-pregnancy BMI may influence more on children’s body composition in long-term than the other GDM risk factors.

There were no statistically significant relationships between pre-pregnancy BMI and children’s PA or SB. There are most likely other factors, such as parental PA and SB (Xu et al. 2015) and education (Muthuri et al. 2016), that influence more on children’s PA. Since a negative association between maternal current BMI and children’s PA (Butte et al. 2014; Muthuri et al. 2016), as well as a positive association with children’s SB (Butte et al. 2014) has been previously reported, it is possible that the mother’s current BMI affects more on children’s PA at early ages than pre-pregnancy BMI. Furthermore, high pre-pregnancy BMI may be more related to overnutrition, and hence, influences rather on their children’s adiposity instead of PA. Since family lifestyle has been reported to improve children’s PA (Butte et al. 2014), future studies are needed to clarify the relationship of pre-pregnancy BMI with children’s PA enabling the use of “teachable moment” during pregnancy.

Strengths and limitations

To our knowledge, this is the first study comparing the absence and presence of GDM risk to the women’s PA and SB as well as to their children’s PA, SB and body composition. The major strength of the study is the somewhat long follow-up period, comparing to previous studies using follow-up periods for up to 12 months (Retnakaran et al. 2010; Evenson et al. 2012). Additionally, PA and SB were measured objectively using validated accelerometer (Aittasalo et al. 2015; Vähä-Ypyä et al. 2015; Tuominen et al. 2016), which provided accurate information on PA and SB in both mothers’ and children. Furthermore, they had on average 6.5-6.7 valid days of accelerometer data per week, which increases the reliability of the measured PA and SB.

The primary weakness of our study is that 28% of the women in GDM risk group received a PA and dietary counseling during pregnancy. The counseling has not been reported to be effective in increasing the weekly duration of PA (Aittasalo et al. 2012) or reducing maternal GDM (Luoto et al. 2011). Nevertheless, the result did not differ essentially when analyses were adjusted for counseling. Secondly, self-reported information on PA is susceptible for misreporting. However, the questionnaire was the same at both measurement points, and therefore misreporting was likely to happen consistently. Finally, self-reported pre-pregnancy weight may have led to underestimation, and further, to underestimation of pre-pregnancy BMI. Due to that, the actual number of overweight women may be higher.

Population-based recruitment and a high participation rate among the preliminarily eligible women (88%) (Aittasalo et al. 2012) improves the generalizability of the findings to the target group. However, it is possible that the women who were physically more active and also more aware of healthier lifestyle participated in the study, in particular in the follow-up. This may have biased the results.

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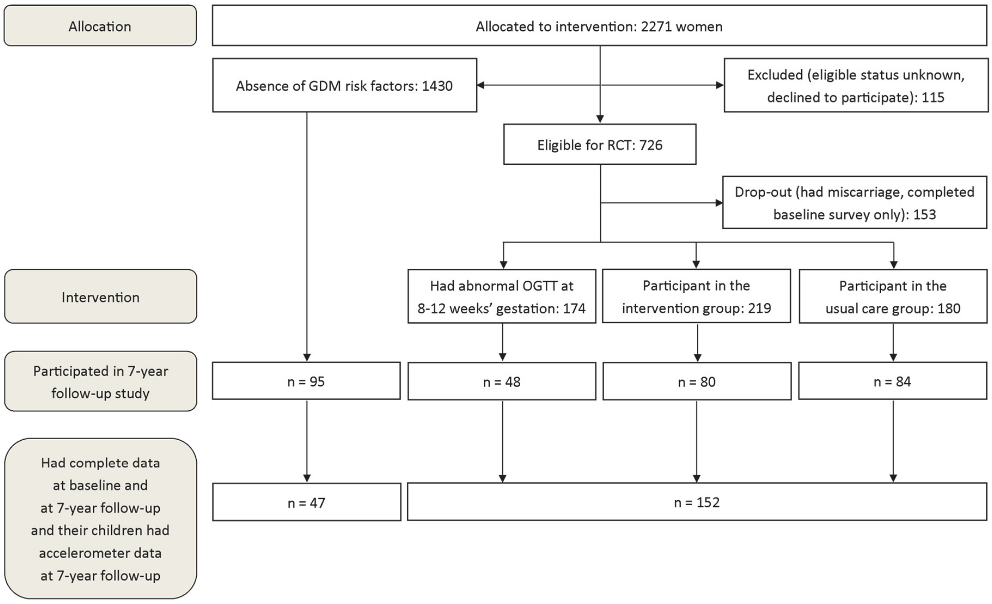

Figure 1. Flow chart of the study.

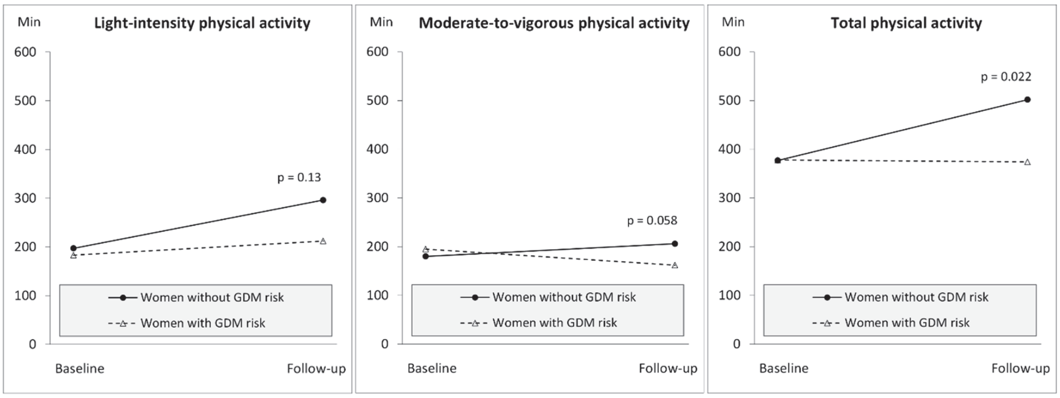

Figure 2. The weekly minutes of change in self-reported intensity-specific physical activity from baseline (pre-pregnancy) to the 7-year follow-up stratified by the women with (n=152) or without (n=47) gestational diabetes (GDM) risk. P-values represents the significance of the difference in change in physical activity over the 7-year follow-up between the groups.

Table 1. Characteristics of the participants, stratified by absence or presence of GDM risk: a) prior to pregnancy (baseline), and b) at 7-year after the delivery (follow-up).

	Absence of GDM risk (N=47)	**Presence of GDM risk[a] (N=152)**	**P-value for difference**
Characteristics at baseline			
Age (years)	29.3 (5.5)	30.2 (4.6)	0.26[b]
Height (cm)	166.6 (6.0)	166.5 (6.6)	0.92[b]
Weight (kg)	61.8 (6.6)	74.2 (14.5)	<0.001[b]
Body mass index, BMI (kg/m^2)	22.3 (2.0)	26.8 (4.9)	<0.001[b]
Education, N (%)			
Academic	13 (28.9)	44 (28.9)	0.96[c]
Polytechnic	19 (42.2)	61 (40.1)	
Basic or secondary school	13 (28.9)	47 (30.9)	
Working status, N (%)			
Fulltime	30 (63.8)	94 (61.8)	0.81[c]
Part-time, unemployed, student, maternity leave	17 (36.2)	58 (38.2)	
Marital status, N (%)			
Married	46 (97.9)	148 (97.4)	0.85[c]
Not married	1 (2.1)	4 (2.6)	
Number of children in the home, N (%)			
0	22 (46.8)	69 (45.7)	0.89[c]
1+	25 (53.2)	82 (54.3)	
GDM risk factors, N (%)			
Age ≥ 40 years	-	3 (2.0)	
Pre-pregnancy BMI ≥25 kg/m^2	-	95 (62.5)	
Newborn's macrosomia[e]	-	4 (2.6)	
GDM or signs of glucose intolerance	-	22 (14.5)	
Family history of diabetes	-	88 (57.9)	
Number of GDM risk factors, N (%)			
1	-	97 (63.8)	
2	-	50 (32.9)	
3+	-	5 (3.3)	
Characteristics at the 7-year follow-up			
Age (years)	37.0 (5.5)	37.8 (4.6)	0.34[b]
Weight (kg)	63.6 (7.2)	77.7 (15.8)	<0.001[b]
Body mass index, BMI (kg/m^2)	22.9 (2.6)	28.1 (5.7)	<0.001[b]
Working status, N (%)			
Fullday	21 (44.7)	101 (66.4)	0.007[c]
Part-time, unemployed, student, maternity leave	26 (55.3)	51 (33.6)	
Marital status, N (%)			
Married	38 (80.9)	120 (78.9)	0.78[c]
Not married	9 (19.1)	32 (21.1)	
Number of children in the home, N (%)			
1	5 (10.6)	15 (10.0)	0.90[c]
2+	42 (89.4)	135 (90.0)	

	47 (55.3)	152 (53.3)	
Children's characteristics, N (boys %)			
Age (years)	6.6 (0.5)	6.5 (0.6)	0.33[b]
Height (cm)	122.7 (5.5)	123.0 (6.0)	0.82[b]
Height for age z-score[f]	0.11 (0.9)	0.37 (1.1)	0.18[b]
Weight (kg)	24.2 (3.6)	24.7 (4.8)	0.82[d]
Weight for age z-score[f]	0.05 (0.9)	0.23 (1.0)	0.31[b]
BMI (kg/m^2)	16.0 (0.2)	16.2 (0.2)	0.56[b]
Overweight or obese[f]	6 (14.6)	31 (21.8)	0.31[c]

Means (standard deviations) or frequencies (%).

[a] Having at least one GDM risk factor.

[b] T-test

[c] Chi-square test

[d] Mann-Whitney U-test

[e] ≥4,500 g in any earlier pregnancy

[f] According to Saari et al. (2011).

Table 2. Linear regression analysis of longitudinal relationships between change in self-reported physical activity (min/week) from baseline to the 7-year follow-up, and demographic factors at baseline among women with and without gestational diabetes risk.

	Light-intensity PA[a]	**MVPA[a]**	**Total PA[a]**
	Unstandardized B coefficient (95% CI)	**Unstandardized B coefficient (95% CI)**	**Unstandardized B coefficient (95% CI)**
Women without GDM risk, unadjusted, N=199	69.0 (-19.4, 157)	60.5 (-2.15, 123)	130 (18.6, 240)*
Women without GDM risk, adjusted[b], N=195	88.2 (20.0, 156)*	41.0 (-6.46, 88.4)	130 (41.9, 217)**
Age	-8.93 (-14.9, -2.92)**	-3.20 (-7.37, 0.98)	-11.8 (-19.6, -4.08)**
Pre-pregnancy BMI	4.02 (-1.97, 10.0)	-1.81 (-6.02, 2.39)	2.48 (-5.28, 10.2)
Education (*Reference basic or secondary school)*			
Polytechnic	25.3 (-40.0, 90.7)	39.9 (-6.58, 84.6)	60.9 (-23.7, 146)
Academic	13.2 (-59.0, 85.4)	28.8 (-21.3, 78.8)	41.9 (-51.0, 135)
Working status (*Reference full day)*			
Part-time, student, unemployed, maternity leave	12.4 (-47.8, 72.5)	6.22 (-34.7, 47.1)	13.3 (-63.6, 90.3)
Children in the home (*Reference at least one)*			
Not at all	-75.1 (-135, -14.9)*	16.8 (-23.6, 57.3)	-63.9 (-140, 12.4)

[a] PA, physical activity; MVPA, moderate-to-vigorous physical activity; CI, confidence interval.

[b] Adjusted for age (continuous), BMI (continuous), education (Academic/polytechnic/basic or secondary school), working status (fulltime/part-time, being a student, unemployed or on maternity leave), and number of children under 7 years (none/at least one) at baseline, and for baseline value of the outcome (continuous).

*P-value <0.05; **P-value <0.01; ***P-value <0.001.

Table 3. Linear regression analysis of cross-sectional relationships of sedentary behavior and physical activity (% of awake wearing time) with demographic factors at 7-year after the delivery among women with and without gestational diabetes risk.

	Sedentary behavior	Light-intensity PA[a]	MVPA[a]
	Unstandardized B coefficient (95% CI)	Unstandardized B coefficient (95% CI)	Unstandardized B coefficient (95% CI)
Women without GDM risk, unadjusted, N=199	-2.68 (-4.84, -0.53)*	1.78 (0.36, 3.21)*	0.90 (-0.14, 1.94)
Women without GDM risk, adjusted[b], N=195	-0.57 (-2.90, 1.76)	0.40 (-1.12, 1.91)	0.17 (-1.02, 1.36)
Age	0.03 (-0.17, 0.23)	-0.03 (-0.15, 0.10)	-0.001 (-0.10, 0.10)
Current BMI	0.20 (0.03, 0.37)*	-0.11 (-0.22, 0.00)	-0.09 (-0.18, -0.01)*
Education (*Reference basic or secondary school)*			
Polytechnic	1.62 (-0.55, 3.80)	-0.90 (-2.31, 0.51)	-0.72 (-1.83, 0.38)
Academic	4.25 (1.83, 6.66)***	-2.99 (-4.56, -1.42)***	-1.26 (-2.48, -0.30)*
Working status (*Reference full day)*			
Part-time, student, unemployed, maternity leave	-2.03 (-3.97, -0.10)*	1.74 (0.49, 3.00)**	0.29 (-0.69, 1.27)
Children in the home (*Reference at least two)*			
One	-1.24 (-4.18, 1.71)	0.77 (-1.15, 2.69)	0.47 (-1.04, 1.96)

[a] PA, physical activity; MVPA, moderate-to-vigorous physical activity; CI, confidence interval.

[b] Adjusted for baseline education (Academic/polytechnic/basic or secondary school) as well as for age, BMI, working status (fulltime/part-time, being a student, unemployed or on maternity leave), and number of children under 7 years (one/at least two) at 7-year after the delivery, and additionally, for awake wearing time of the accelerometer.

*P-value <0.05; **P-value <0.01; ***P-value <0.001.

III

PHYSICAL ACTIVITY INTENSITY, SEDENTARY BEHAVIOR, BODY COMPOSITION AND PHYSICAL FITNESS IN 4-YEAR-OLD CHILDREN: RESULTS FROM THE MINISTOP TRIAL

by

Leppänen, M. H., Nyström, C. D., Henriksson, P., Pomeroy, J., Ruiz, J. R.,
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Physical activity intensity, sedentary behavior, body composition and physical fitness in 4-year-old children: Results from the MINISTOP trial

Running head: Activity and body composition in 4-year-olds

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ABSTRACT

Background: Existing knowledge on associations of physical activity (PA) and sedentary behavior (SB) with body composition and physical fitness in preschoolers is limited.

Objective: To examine associations of PA and SB with body composition and physical fitness in healthy Swedish 4-year-old children.

Methods: We utilized baseline data collected in 2014 for the population-based MINISTOP trial (n=307). Light-intensity PA (LPA), moderate-intensity PA (MPA), vigorous-intensity PA (VPA), moderate-to-vigorous PA (MVPA), and SB were measured using accelerometry (ActiGraph-wGT3x-BT). Body composition was measured using air-displacement plethysmography, and physical fitness (i.e. cardiorespiratory fitness, lower and upper body muscular strength, and motor fitness) was measured using the PREFIT fitness test battery. Multiple linear regression models adjusted for relevant confounders, and in addition, isotemporal substitution models were applied.

Results: Greater MVPA was associated with lower fat mass percent (%FM) ($p=0.015$), and greater VPA and MVPA were associated with higher fat-free mass index (FFMI) ($p=0.002$ and $p=0.011$). In addition, greater VPA and MVPA were associated with higher scores for all physical fitness tests ($p=0.042$ to $p<0.001$). The results for MVPA were primarily due to VPA. SB was associated with weaker handgrip strength ($p=0.031$) when PA was not adjusted, but after adjusting also for VPA, the significant association disappeared ($p=0.25$). Substituting 5 minutes/day of SB, LPA or MPA with 5-minutes/day of VPA was associated with higher FFMI and better scores for cardiorespiratory fitness and motor fitness. Correspondingly, substituting 5-minute/day of VPA with SB or LPA was associated with weaker performance for lower muscular strength.

Conclusions: Time spent on VPA was associated with higher FFMI and better physical fitness. The results suggest that promoting VPA may be important in order to improve childhood body composition and physical fitness already at an early age.

INTRODUCTION

Childhood obesity is a serious public health problem globally[1], and it has been associated with many physical and psychological consequences[2]. Obesity may be established already at pre-school age[3] hence we need interventions early in life to counteract an accumulation of body fat. In order to design such interventions modifiable risk factors should be identified, and due to its' influence on energy balance, physical activity (PA) is likely an important factor to consider in this context. However, few studies have investigated associations between objectively measured PA and body composition in preschoolers[4-7]. These studies indicate a negative relationship of high-intensity PA with adiposity[4,6,7], and with the odds of being overweight[5,7]. However, results for sedentary behavior (SB) and adiposity are somewhat inconsistent[4,6,8] with null associations for objectively assessed SB[4], and a positive association of SB with waist circumference in girls[8]. The technology of accelerometers has improved, enabling data collection over shorter time intervals (5- to 15-seconds instead of minutes) which is recommended for young children since their activity is characterized by shorter outbursts of PA[9]. However, the use of epoch lengths varies between previous studies from 5-seconds[7] and 15-seconds[8] to 60-seconds epochs[4-6], and in addition, the use of uniaxial instead of triaxial accelerometers may attenuate the observed associations.

Physical fitness, particularly cardiorespiratory fitness and muscular strength, has been considered an important marker of health in children and adolescents[10,11]. For example, improvements in cardiorespiratory fitness have been associated with a reduced risk of being overweight or obese in puberty[12], as well as improved cardiorespiratory health in adulthood[9]. Muscular strength has been positively associated with psychological health[13], and decreased all-cause premature mortality[14]. To date, research on physical fitness has focused on adults or older children, and only a few studies have examined associations between PA and physical fitness in preschoolers[15,16], and only single tests were used. In 2014, we proposed an evidence-based fitness test battery appropriate for children aged 3-5 years[17] covering cardiorespiratory and motor fitness as well as upper and lower muscular strength.

In the present study we investigated whether accelerometer-derived PA intensities as well as SB are associated with fatness and fitness in Swedish 4-year-olds. We hypothesized that higher PA levels would be associated with lower levels of fat mass and higher fat-free mass as well as better physical fitness.

SUBJECTS AND METHODS

Study design and participants

The present study utilizes baseline data from the MINISTOP trial collected in 2014[18,19]. The recruitment, methods and inclusion and exclusion criteria of the MINISTOP trial have been described in detail by Delisle et al.[18]. Briefly, the population-based trial is a two-arm, parallel design randomized controlled trial in 315 healthy Swedish 4-year-old children. The 6- month intervention consists of a mobile phone-based application (the MINISTOP app) to help parents promote healthy eating and PA in children. For baseline assessments, the parents brought their child to the hospital for measurements of body composition and physical fitness, and the children were asked to wear the accelerometer for 24-h for seven days after this visit. Parents reported their age, body weight, height, and education by means of a questionnaire. For the present analysis, children with insufficient accelerometer data (n=8) were excluded. Thus, the final analysis included 307 children, and all data used were obtained before randomization and delivery of the intervention. Informed consent, witnessed and formally recorded, was obtained from all parents, and the trial (registered 20 Dec 2013 in clinicaltrials.gov NCT02021786) was approved by the Research Ethics Committee, Stockholm, Sweden (2013/1607–31/5; 2013/2250–32).

Data collection

Physical activity and sedentary behavior

PA and SB were continuously assessed for 24-h over seven consecutive days using the ActiGraph wGT3x-BT triaxial accelerometer (www.actigraphcorp.com) on the non-dominant wrist. Parents were asked to record in a notebook when the device was taken off and the activities performed during that period (i.e. showering/bathing/swimming). The monitors were set to sample at 50Hz. In accordance with the previous findings by Collings et al.[4], the PA levels in our 307 children were similar on both week and weekend days (data not shown). Hence, regardless of the day of the week, children with at least three days of valid activity data were included in the analyses. A valid day was defined as ≥ 600 minutes of awake wearing time[4].

Non wear time was determined using the raw acceleration data. The standard deviation (SD) of each axis was calculated over a 30 minute moving window. If the SD of acceleration of any two axes was less than 0.002 g for the same window that period was marked as non wear time. This approach was adapted from van Hees et al.[20] and the SD cut-offs for non wear time for the wGT3X-BT monitors were derived by placing 5 monitors on a table top to record for 4 hours undisturbed as well as by placing 5 monitors inside a backpack to record for 4 hours undisturbed. The cut-off chosen was greater than the largest SD recorded during the controlled non wear time situations and less than the smallest

SD recorded during known worn time that included sleep (data not shown). Time scored as worn was classified into sleep or awake time using the Sadeh algorithm[21,22].

We used ActiLife software (version 6.11.2) to process the raw data to derive filtered sum of vector magnitudes (VM) in 10 second epochs. We applied two ways to assess PA intensities. Firstly, for each child, the 25th, 50th (median), 75th, 90th and 95th percentiles of 10 second sum of VM during awake time that the monitor was worn, were calculated. These variables provide an estimate of the children's time spent in intensity-specific PA percentiles of being physically active (e.g. 95 %, 90 %, 75 %, 50 % and 25 % of their time) in intensity-specific level during their awake time. The advantage of these VM percentiles are that they avoid some limitations inherent in defining PA intensities using predefined cut-off levels. For each child we also calculated the time spent (min/day) in intensity-specific PA levels and in SB. The cut-points for SB were defined as VM <305, for light-intensity PA (LPA) as VM 306-817, for moderate-intensity PA (MPA) as VM 818-1968, for vigorous-intensity PA (VPA) as VM > 1969, and for moderate-to-vigorous PA (MVPA) as VM > 818 (all per 5 seconds) in accordance with Chandler et al.[23].

Body composition and anthropometry

Body composition was assessed using air-displacement plethysmography by means of the pediatric option for BodPod (www.cosmed.com)[24]. Body density was calculated from body volume and body weight. Subsequently, body fatness was calculated by applying appropriate densities for fat and fat-free mass[25]. The body composition measures included were body mass index (BMI), fat mass index (FMI), fat-free mass index (FFMI) and percent fat mass (% FM). BMI was calculated as body weight (kg)/height^2 (m), FMI as fat mass (kg)/height^2 (m), and FFMI as fat-free mass (kg)/height^2 (m). Height and waist circumference were measured using standardised procedures as previously described[19].

Physical fitness

Physical fitness measures were evaluated using four tests within the PREFIT fitness test battery: 1) a 20 m shuttle run test for cardiorespiratory fitness, 2) a handgrip strength test for upper body muscular strength, 3) a standing long jump test for lower body muscular strength, and 4) a 4x10 m shuttle run test for motor fitness. The PREFIT test battery is based on a systematic review about the reliability and validity of physical fitness tests in preschool children[17]. All tests were applied twice, except the 20 m shuttle run test that was only conducted once. For the handgrip strength test, the best value of the two attempts for each hand was chosen, and the average of both hands was used in the analyses. For the standing long jump and the 4x10 m shuttle run tests, the best values of two attempts were used in the analysis. The details of the procedures for the physical fitness tests have been previously published[19].

Statistical methods

Descriptive information is given as arithmetic means and SD or frequencies and percentages. Multiple linear regression was used to assess the association between a) 95th, 90th, 75th, 50th and 25th percentiles of VM, and b) SB and intensity-specific PA (LPA, MPA, VPA and MVPA) with body composition measurements and physical fitness tests. At first, we fitted unadjusted models and, subsequently, each model was adjusted for maternal BMI (continuous), maternal educational attainment (university degree or no university degree), paternal BMI (continuous), paternal educational attainment (university degree or no university degree), child’s sex (boy or girl) and age (continuous) at the measurement, and awake wearing time of the ActiGraph (continuous) due to potential effect on body composition and physical fitness. Finally, the models with SB and intensity-specific PA models were further adjusted for other PAs. Models with SB, LPA and MPA as exposures were adjusted for VPA, while models with VPA and MVPA were adjusted for SB.

ex comparisons between average values were made by using independent t-test for continuous variables, and chi-square test for categorized variables. We also investigated if the associations differed by sex by adding an interaction term (type of PA x child's sex) to the adjusted regression models. For these analyses, we considered $p<0.01$ as level for significance for the interaction terms to control for multiple comparisons. We did not find any evidence for any sex interactions and consequently we present the results for boys and girls together.

In supplementary analyses, we fitted isotemporal substitution models as described by Mekary et al.[26] to estimate the effect of substituting one PA type with another PA type for the same amount of time (e.g., substituting LPA with MPA, by taking LPA out of the model).

Control of regression models showed that required assumptions (existence, independence, linearity, homoscedasticity and normality)[27] were not violated. All statistical tests were conducted using the two sided 5 % level of significance and performed using SPSS Statistics 20 (IBM, Armonk, NY, USA).

Power considerations and sample size

As previously reported[18], the MINISTOP trial was dimensioned to provide sufficient power to evaluate if the intervention is effective. For this analysis, we considered that a sample size of 300 yields a power of 0.80 (two-tailed) to detect a standardized regression coefficient of 0.16.

RESULTS

Characteristics of the participants

The average age of the participating children's mothers was 36 years (SD 4.3), height 1.67 m (SD 0.06), weight 68 kg (SD 12.9), BMI 24.4 kg/m^2 (SD 4.4), and more than half of them (n= 217, 70.7%) had a university degree. The fathers average age was 38 years (SD 5.2), height 1.81 m (SD 0.07), weight 83 kg (SD 12.7), BMI 25.4 kg/m^2 (SD 3.4), and more than half of them (n=176, 57.3%) had a university degree.

Table 1 describes age, anthropometric variables, body composition, PA, SB and physical fitness for the 307 children. The children covered a wide range of body composition and accelerometer outputs as well as physical fitness. Valid accelerometer data were obtained for 3 (2.6%), 4 (2.0%), 5 (3.9%), 6 (10.7%) and 7 (81.1%) days for the children.

Associations between PA intensities as percentiles VM, body composition and physical fitness

Table 2 presents the associations between PA intensities as percentiles VM (95th, 90th and 75th) and body composition and physical fitness measurements. A higher 90th percentile VM was negatively associated with significantly lower %FM (adjusted coeff. -0.25%, $p=0.047$). In addition, a higher 95th and 90th percentile VM were both positively associated with a significantly higher FFMI (adjusted coeff. 0.07 kg/m^2, $p<0.001$; 0.08 kg/m^2, $p=0.003$, respectively). Furthermore, a higher 95th and 90th were all associated with better performance on all physical fitness tests. In contrast, no significant associations were observed between the 50th and 25th percentile VM and body composition measurements or physical fitness tests (data not shown).

Association of SB and PA intensities as LPA, MPA and VPA with body composition

Table 3 shows the associations between SB, MPA, VPA and MVPA and body composition. Greater MVPA was significantly associated with lower %FM, when adjusting for confounders and SB. More specifically, a 5-minute/day greater MVPA was associated with 0.25 ($p=0.015$) lower %FM. Correspondingly, a 5-minute/day greater VPA and MVPA were associated with 0.19 ($p=0.002$) and 0.06 kg/m^2 ($p=0.011$) higher FFMI. In contrast, no significant associations between SB, LPA (data not shown) or MPA and %FM or FFMI were observed.

The results of the isotemporal substitution analyses (Table 4) showed that substituting 5-minutes/day of SB, LPA or MPA with 5-minutes/day of VPA was associated with a 0.16-0.18 kg/m^2 higher FFMI. No statistically significant associations for BMI, FMI or %FM when substituting any of the PAs were observed (data not shown).

Association of SB and PA intensities as LPA, MPA and VPA with physical fitness

Associations between times spent in SB, MPA, VPA and MVPA with each physical fitness test are also shown in Table 3.

Cardiorespiratory fitness: Greater VPA and MVPA were both significantly associated with better performance in the 20 m shuttle run test when adjusting for confounders and SB. In detail, 5-minutes/day greater VPA and MVPA were associated with 0.96 ($p<0.001$) and 0.24 ($p<0.001$) more laps, respectively. However, no significant association between SB, LPA (data not shown) or MPA and laps for the 20 m shuttle run were observed. As shown in Table 4, substituting 5-minutes/day of SB, LPA or MPA with 5-minutes/day of VPA were associated with nearly one lap better score in the 20 m shuttle run ($p<0.001$).

Upper muscular strength: A 5-minute greater VPA was associated with nearly 200g better handgrip strength score (p= 0.042, Table 3) when adjusting for confounders and SB. Furthermore, a greater MVPA was associated with a 70-g better handgrip strength score, but it did not reach statistical significance (p=0.061). However, the isotemporal substitution analyses did not reveal any significant associations when substituting one of the PA intensities with another (Table 4).

Lower muscular strength: A 5-minute/day greater VPA and MVPA were associated with jumping over three centimeters (p=0.001) and 1.2 centimeters (p<0.001) longer in the standing long jump test, respectively (Table 3). SB, LPA (data not shown) or MPA were not significantly associated with standing long jump. As shown in Table 4, substituting 5-minutes/day of VPA with 5-minutes/day of SB or LPA were associated with over a two centimeter higher score in the standing long jump test (p<0.05).

Motor fitness: Greater VPA and MVPA were both associated with better performance (i.e. lower score) in the 4x10 m shuttle run test when adjusting for confounders and SB (Table 3). More specifically, a 5-minute greater VPA and MVPA were associated with 0.67 (p<0.001) and 0.16, (p<0.001) seconds faster time. However, no significant association between SB, LPA (data not shown) or MPA and the 4x10 m shuttle run test were discovered. Substituting 5-minutes/day of SB, LPA and MPA with 5-minutes/day of VPA was associated with over 0.60 seconds faster time in the 4x10 m shuttle run (p<0.001) (Table 4).

DISCUSSION

Our principal finding is that VPA was associated with higher FFMI as well as higher scores for all fitness tests. Since physical fitness is an important marker of health[10,11], the results highlight the need to enhance VPA already in preschoolers. SB itself was not associated with body composition or physical fitness, however, the association may be indirect. The time spent in SB is away from PA, which may enhance physical fitness and body composition, and in addition, SB, such as TV viewing, has been associated with a higher energy intake already in preschoolers[28].

We found that MVPA was negatively associated with %FM, while VPA and MVPA were positively associated with FFMI. In addition, substituting 5 minutes/day of SB, LPA or MPA with VPA was associated with a 0.16-0.18 kg/m^2 higher FFMI. These are quite strong associations since 0.16-0.18 kg/m^2 represents 0.2 SD in FFMI i.e. a substantial amount of the total variation in FFMI. It is difficult to directly compare these results with other studies due to differences in the methodology applied for PA and body composition. However, our findings are partly in line with Collings et al.[4] who reported negative associations for VPA and MVPA with total adiposity but no association between PA and FFMI. Janz et al.[6] also found negative associations between VPA and %FM, and a significant positive association between MVPA and FFMI (in girls). One plausible explanation for the somewhat different results for FFMI is that we used a triaxial accelerometer and shorter epochs as recommended for young children, which have captured PA more closely[9]. Thus, we provide novel findings about the association between PA and body composition using accurate methodology. Our findings provide useful information for intervention studies and suggest that increasing VPA in preschool children might be effective in preventing childhood obesity, and possibly obesity in adulthood[29].

We found no association between PA and FMI, which is contradictory to a previously published study[4], who has reported negative associations between MVPA, VPA and FMI[4]. It may appear intriguing that we observed a negative association between MVPA and %FM but not between MVPA and FMI. Firstly, it is relevant to note that associations between MVPA and %FM were not very strong (adjusted b coefficient -0.25 % per 5 minute greater MVPA which represents 0.06 SD in %FM) and the corresponding adjusted b coefficient for MVPA and FMI was -0.04 kg/m^2 (representing 0.04 SD in FMI). Secondly, our results primarily indicate strong associations of MVPA and VPA with FFMI. One contributing reason for the somewhat weaker association for FMI is that %FM reflects not only the proportion of total body fat, but also the proportion of fat-free mass in the body[30].

Similar to Collings et al.[4], we found no association between SB and body composition. This is in contrast to Janz et al.[6] who reported a negative association between TV viewing and %FM. The contradictory results may be due to the methodological differences, since in their study, the amount of TV viewing was based on parental self-report. However, we observed that substituting SB, LPA or MPA with VPA was associated with significantly higher FFMI. This is an interesting finding, and highlights the need to look at the associations after substituting one PA intensity with another.

To our knowledge, this is the first study to examine the association of accelerometer-derived PA with all types of physical fitness in preschool aged children. VPA was strongly associated with all four types of physical fitness. Our results are in accordance with previously published studies concerning associations between PA and single fitness tests in preschool children[15,31]. Bayer et al.[15] reported that a higher self-reported PA was positively associated with number of jumps in a motor test in German preschool children. In addition, participating in a sport club was associated with a higher level of PA and cardiorespiratory fitness in Swiss preschoolers[31].

In contrast to the results for the other fitness tests, the isotemporal substitution analyses did not show any improvements in upper body muscular strength when substituting SB and LPA for VPA. We can only speculate why this occurred, but it is logical since VPA was not as strongly associated with upper body muscular strength as with the other fitness tests. The popular types of VPA in young children (running, cycling etc.) may focus more on lower body muscles and therefore, strengthens these muscles instead of upper body muscles. It is also relevant to note that a previous study in older children (12.5–17.5 years) found only a weak association between VPA and upper muscular strength in boys[32].

Overall, our models in Table 3 with body composition variables (%FM and FFMI) and all physical fitness tests revealed statistically significant associations for VPA and in most cases also for MVPA although the associations were generally weaker. No associations were observed for MPA and body composition or physical fitness variables. It is thus reasonable to conclude that it is primarily VPA that is more strongly associated with a higher FFMI and improved physical fitness. No comparable data for physical fitness exists but this conclusion is in line with previous findings for body composition[4] and it is also supported by the isotemporal substitution results.

The major strengths are that we applied accurate and up-to-date methodology for measuring PA, SB, body composition and physical fitness. Furthermore, we analyzed accelerometer data using cut-points and VM percentiles as well as applied isotemporal substitution analyses and all these found similar results. Our study also has limitations. Firstly, we applied cut-points derived in 8-12-year-old children[23] to assess SB, LPA, MPA and VPA since no cut-points for wrist-worn wGT3x-BT recordings for our specific age group are currently available. Another option would have been to apply the cut-points derived in 15-36 month old children published by Johansson et al.[33], but we chose the Chandler cut-points since our 4.5 year-old children's motor skills are more similar to 8-12 year-olds than to 15 -36 month-olds. However, we also calculated SB and PA intensities using the cut-points by Johansson et al.[33], and our major results and conclusions would have been similar when using those cut-points (data not shown). Furthermore, our results in Table 3 were supported by the results when fitting models using percentiles of VM (Table 2). To conclude, even though our results need confirmation when ActiGraph wGT3x wrist-worn cut-points for 4-5 year-olds are available, we find it unlikely that our choice of cut-points have affected our results and conclusions in any major way. Another limitation is that we conducted many comparisons creating a risk for type 1 errors. Finally, due to the cross-sectional setting, reverse causation cannot be excluded: the children with better physical fitness have the stamina to be more physically active. Correspondingly, lower FFMI and higher adiposity may predict lower PA. In support for the latter, Li et al.[34] reported that infant adiposity constrained subsequent PA level. To further elucidate the true directions of the associations between body composition, PA and physical fitness in young children, longitudinal studies are warranted.

The generalizability of our results also deserves some comments. As common in research, our parents were slightly better educated (58% men and 71% women had a university degree vs. 39% and 52% in the general population)[35]. Since, high parental education has reported to be associated with a higher performance in motor testing in preschoolers[15], this may limit generalizability. However, the prevalence of overweight and obesity among our parents was in accordance with the Swedish population[36]. Furthermore, the children's body size and prevalence of overweight and obesity was comparable to Swedish national data[37,38] and all of them attended day care which is similar to that of Swedish children in general (93%)[39].

This study reports many statistically significant associations; however, the clinical significance of the findings also needs to be addressed. The strengths of the associations can be judged by evaluating the magnitude of the adjusted coefficients in relation to a defined change in the x-variable (VPA). Thus, the strengths of our associations were as follows: a 5 minute/day greater VPA was associated with a higher FFMI (adjusted coefficient: +0.2 kg/m^2) and with a better performance in the 20 m shuttle run (adjusted coefficient: +1 lap), standing long jump (adjusted coefficient: +3 cm), handgrip strength (adjusted coefficient: +200 gram) and 4 x 10 m shuttle run tests (adjusted coefficient: -0.7 seconds). Thus, as little as a 5-minute/day increase in VPA, was associated with a substantial amount in the study outcomes, especially when considering the observed variation (i.e. standard deviations) in these outcomes. Therefore, it can be concluded that the strengths of our associations may be relevant from a clinical point of view. Our results cannot be used as a basis for recommendations to individual children since this is a cross-sectional design and a single study. However, they do indicate that the observed associations may be strong enough to have some clinical significance and that they are probably strong enough to have public health importance. These findings are also very informative for planning future intervention studies.

In conclusion, greater VPA was associated with a higher FFMI and better scores for all physical fitness tests in healthy Swedish 4-year-old children. The results suggest that enhancing VPA may play an important role in improving childhood body composition and physical fitness already in preschool aged children.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Table 1. Descriptive characteristics of the children.

Characteristics	All (N=307)		Boys (N=170)		Girls (N=137)		
	n	Value	n	Value	n	Value	P-sex difference
Age (years)	307	4.48 ± 0.15	170	4.49 ± 0.15	137	4.47 ± 0.15	0.43
Height (cm)	307	108 ± 4.21	170	108 ± 4.33	137	107 ± 4.03	0.18
Height for age z-score[1]	307	-0.03 ± 0.97	170	0.01 ± 0.98	137	-0.09 ± 0.95	0.37
Weight (kg)	307	18.3 ± 2.47	170	18.5 ± 2.38	137	18.1 ± 2.56	0.21
Weight for age z-score[1]	307	-0.06 ± 1.10	170	-0.06 ± 1.11	137	-0.06 ± 1.10	0.97
BMI (kg/m^2)	307	15.8 ± 1.36	170	15.8 ± 1.29	137	15.7 ± 1.44	0.44
Overweight / Obese (%)[2]	26	8.5	13	7.6	13	9.5	0.56
Waist circumference (cm)	304	53.6 ± 3.66	169	53.5 ± 3.58	135	53.6 ± 3.78	0.92
Fat mass (%)[3]	295	26.0 ± 4.46	166	25.0 ± 3.92	129	27.4 ± 4.73	<0.001
Fat mass index (kg/m^2)[3]	295	4.13 ± 0.92	166	3.97 ± 0.80	129	4.34 ± 1.02	0.001
Fat-free mass index (kg/m^2)[3]	295	11.6 ± 0.97	166	11.9 ± 0.96	129	11.4 ± 0.92	<0.001
Fitness tests' characteristics							
20 meter shuttle run (laps)[3]	299	5.78 ± 2.56	164	5.67 ± 2.61	135	5.92 ± 2.50	0.41
Handgrip strength (kg)[3]	305	6.45 ± 1.60	170	6.78 ± 1.64	135	6.04 ± 1.44	<0.001
Standing long jump (cm)[3]	306	71.6 ± 15.3	170	72.3 ± 15.7	136	70.8 ± 14.7	0.40
4x10 meter shuttle run (sec)[4]	307	18.2 ± 1.95	170	18.2 ± 2.15	137	18.1 ± 1.67	0.56
ActiGraph characteristics							
Valid days[5]	307	6.65 ± 0.86	170	6.74 ± 0.69	137	6.55 ± 1.02	0.059
Sum of awake VM	307	389 ± 58.0	170	391 ± 61.9	137	386 ± 53.7	0.53
Awake wearing time (min/day)	307	842 ± 56.1	170	841 ± 58.8	137	843 ± 52.8	0.80
Sedentary behavior (min/day) [6]	307	479 ± 49.6	170	478 ± 50.2	137	481 ± 49.1	0.58
Light PA (min/day) [6]	307	261 ± 28.4	170	261 ± 28.4	137	260 ± 28.5	0.58
Moderate PA (min/day) [6]	307	94.1 ± 22.5	170	93.3 ± 23.6	137	95.2 ± 21.1	0.47
Vigorous PA (min/day) [6]	307	7.4 ± 4.9	170	8.1 ± 5.6	137	6.6 ± 3.8	0.004
Moderate-to-vigorous PA (min/day) [6]	307	101 ± 25.2	170	101 ± 27.0	137	102 ± 22.8	0.92
95th percentile VM[7]	307	2204 ± 290	170	2228 ± 327	137	2175 ± 235	0.11
90th percentile VM[7]	307	1737 ± 200	170	1744 ± 224	137	1729 ± 166	0.51
75th percentile VM[7]	307	1145 ±136	170	1145 ± 144	137	1145 ± 125	0.99
50th percentile VM[7]	307	600 ± 107	170	602 ± 108	137	596 ± 107	0.60

25th percentile VM[7]	307	146 ± 69.6	170	147 ± 66.3	137	144 ± 73.7	0.68

Data are given as mean ± SD or n (%). VM, vector magnitude.

[1] Calculated using Swedish reference data[37].

[2] According to the Cole et al.[40].

[3] A few children did not comply with the study protocol for the body composition measurements (n=12), waist circumference (n=3), handgrip strength test (n=2), standing long jump test (n=2), and for the 20 m shuttle run test (n=8).

[4] The lower the score (in seconds), the higher the performance.

[5] Defined as ≥ 600 minutes of awake wearing time[4].

[6] Classified according to Chandler et al.[23].

[7] The percentiles are given per 10 second sum of vector magnitudes (VM) and refer to as 95th, 90th, 75th, 50th, and 25th percentile VM.

Sex comparisons were made by using t-test, except chi-square test for categorized variables (overweight/obese).

Table 2: Associations between physical activity intensities[1] and body composition and physical fitness.

	95th percentile VM		90th percentile VM		75th percentile VM	
	b (95% CI)	p	b (95% CI)	p	b (95% CI)	p
Measures of body composition						
BMI (kg/m^2)						
Unadjusted	0.04 (-0.01, 0.10)	0.11	0.04 (-0.04, 0.12)	0.30	0.02 (-0.10, 0.13)	0.77
Adjusted[2]	0.04 (-0.01, 0.10)	0.096	0.05 (-0.03, 0.12)	0.22	0.04 (-0.07, 0.15)	0.49
FM (%)[3]						
Unadjusted	-0.23 (-0.41, -0.06)	0.009	-0.32 (-0.57, -0.06)	0.015	-0.31 (-0.69, 0.07)	0.11
Adjusted[2]	-0.17 (-0.34, 0.00)	0.054	-0.25 (-0.51, -0.00)	0.047	-0.26 (-0.63, 0.12)	0.18
FMI (kg/m^2)[3]						
Unadjusted	-0.03 (-0.06, 0.01)	0.17	-0.04 (-0.09, 0.02)	0.17	-0.04 (-0.12, 0.04)	0.33
Adjusted[2]	-0.02 (-0.05, 0.02)	0.43	-0.03 (-0.08, 0.03)	0.34	-0.02 (-0.10, 0.05)	0.54
FFMI (kg/m^2)[3]						
Unadjusted	0.08 (0.04, 0.11)	<0.001	0.09 (0.03, 0.14)	0.002	0.07 (-0.01, 0.15)	0.097
Adjusted[2]	0.07 (0.03, 0.10)	<0.001	0.08 (0.03, 0.13)	0.003	0.08 (-0.00, 0.15)	0.064
WC (cm)[3]						
Unadjusted	0.08 (-0.06, 0.23)	0.26	0.12 (-0.09, 0.33)	0.27	0.13 (-0.18, 0.44)	0.42
Adjusted[2]	0.07 (-0.07, 0.21)	0.30	0.12 (-0.08, 0.32)	0.25	0.17 (-0.13, 0.46)	0.27
Measures of physical fitness						
Cardiorespiratory fitness						
20 m shuttle run (laps)						
Unadjusted	0.28 (0.19, 0.38)	<0.001	0.34 (0.20, 0.48)	<0.001	0.31 (0.09, 0.52)	0.005
Adjusted[2]	0.27 (0.17, 0.36)	<0.001	0.31 (0.17, 0.45)	<0.001	0.25 (0.03, 0.47)	0.024
Upper muscular strength						
Handgrip strength (kg)						
Unadjusted	0.11 (0.05, 0.17)	0.001	0.15 (0.06, 0.24)	0.001	0.17 (0.03, 0.30)	0.014
Adjusted[2]	0.09 (0.03, 0.15)	0.003	0.13 (0.05, 0.22)	0.002	0.17 (0.04, 0.29)	0.010
Lower muscular strength						
Standing long jump (cm)						

Unadjusted	1.18 (0.60, 1.76)	<0.001	1.48 (0.63, 2.32)	0.001	1.33 (0.07, 2.59)	0.039
Adjusted[2]	1.01 (0.43, 1.60)	0.001	1.25 (0.39, 2.10)	0.004	1.05 (-0.22, 2.32)	0.11
Motor fitness						
4x10 m shuttle run (sec)						
Unadjusted	-0.20 (-0.27, -0.12)	<0.001	-0.24 (-0.35, -0.14)	<0.001	-0.21 (-0.37, -0.05)	0.010
Adjusted[2]	-0.18 (-0.26, -0.11)	<0.001	-0.23 (-0.33, -0.12)	<0.001	-0.19 (-0.35, -0.03)	0.021

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[1] The percentiles are given per 10 second sum of vector magnitudes (VM) and refer to as 95th, 90th, 75th percentile VM. The b coefficients given in the table provide estimates of the change in the y-variables (body composition or fitness) associated with a 100 unit change in the x-variables (95th, 90th, 75th percentile VM).

[2] Adjusted for maternal BMI, maternal educational attainment (university degree/ no university degree), paternal BMI, paternal educational attainment (university degree/no university degree), child's sex and age at measurement, and awake wearing time. In addition, WC was adjusted for height.

[3] FM, fat mass; FFMI, fat-free mass index; FMI, fat mass index; WC, waist circumference.

Table 3: Associations between accelerometer-derived physical activity[1] intensities and body composition and physical fitness per five minute change.

	Time spent on SB[2] (min/day)		Time spent on MPA[2] (min/day)		Time spent on VPA[2] (min/day)		Time spent on MVPA[2] (min/day)	
	b (95% CI)	p	b (95% CI)	p	b (95% CI)	p	b (95% CI)	p
Measures of body composition								
BMI (kg/m^2)								
Unadjusted	-0.00 (-0.02, 0.01)	0.63	0.00 (-0.03, 0.04)	0.87	0.13 (-0.03, 0.28)	0.11	0.01 (-0.02, 0.04)	0.65
Adjusted model 1[3]	-0.01 (-0.03, 0.01)	0.49	0.01 (-0.02, 0.05)	0.48	0.12 (-0.03, 0.28)	0.12	0.02 (-0.02, 0.05)	0.35
Adjusted model 2[4]	-0.00 (-0.02, 0.02)	0.95	-0.00 (-0.04, 0.04)	0.94	0.12 (-0.05, 0.29)	0.16	0.02 (-0.04, 0.08)	0.51
FM (%)[2]								
Unadjusted	0.01 (-0.04, 0.07)	0.60	-0.08 (-0.19, 0.04)	0.18	-0.70 (-1.21, -0.18)	0.008	-0.09 (-0.19, 0.01)	0.087
Adjusted model 1[3]	0.01 (-0.06, 0.07)	0.77	-0.08 (-0.20, 0.04)	0.19	-0.46 (-0.98, 0.06)	0.081	-0.08 (-0.19, 0.02)	0.13
Adjusted model 2[4]	-0.02 (-0.09, 0.05)	0.65	-0.04 (-0.17, 0.10)	0.60	-0.51 (-1.08, 0.05)	0.076	-0.25 (-0.45, -0.05)	0.015
FMI (kg/m^2)[2]								
Unadjusted	0.00 (-0.01, 0.01)	0.86	-0.01 (-0.03, 0.01)	0.43	-0.08 (-0.19, 0.03)	0.14	-0.01 (-0.03, 0.01)	0.32
Adjusted model 1[3]	-0.00 (-0.02, 0.01)	0.85	-0.01 (-0.03, 0.02)	0.55	-0.04 (-0.15, 0.07)	0.45	-0.01 (-0.03, 0.01)	0.50
Adjusted model 2[4]	-0.00 (-0.02, 0.01)	0.58	-0.00 (-0.03, 0.03)	0.80	-0.06 (-0.17, 0.06)	0.36	-0.04 (-0.08, 0.01)	0.10
FFMI (kg/m^2)[2]								
Unadjusted	-0.01 (-0.02, 0.01)	0.29	0.02 (-0.01, 0.04)	0.22	0.23 (0.12, 0.34)	<0.001	0.02 (-0.00, 0.04)	0.060
Adjusted model 1[3]	-0.01 (-0.02, 0.01)	0.28	0.02 (-0.00, 0.05)	0.075	0.19 (0.08, 0.30)	0.001	0.03 (0.00, 0.05)	0.024
Adjusted model 2[4]	0.00 (-0.01, 0.02)	0.77	0.00 (-0.03, 0.03)	0.87	0.19 (0.08, 0.31)	0.002	0.06 (0.01, 0.10)	0.011
WC (cm)[2]								
Unadjusted	-0.02 (-0.06, 0.03)	0.47	0.05 (-0.05, -0.14)	0.32	0.17 (-0.26, 0.59)	0.44	0.04 (-0.04, 0.13)	0.30
Adjusted model 1[3]	-0.03 (-0.08, 0.02)	0.25	0.07 (-0.03, 0.16)	0.16	0.14 (-0.27, 0.55)	0.50	0.06 (-0.03, 0.14)	0.17
Adjusted model 2[4]	-0.03 (-0.08, 0.03)	0.33	0.07 (-0.04, 0.18)	0.22	0.05 (-0.40, 0.50)	0.83	0.06 (-0.10, 0.22)	0.46
Measures of physical fitness								
Cardiorespiratory fitness								
20 m shuttle run (laps)								
Unadjusted	-0.01 (-0.04, 0.02)	0.41	0.10 (0.04, 0.16)	0.003	0.90 (0.62, 1.18)	<0.001	0.11 (0.06, 0.17)	<0.001
Adjusted model 1[3]	-0.03 (-0.06, 0.01)	0.18	0.09 (0.02, 0.16)	0.016	0.89 (0.60, 1.17)	<0.001	0.10 (0.04, 0.17)	0.001
Adjusted model 2[4]	0.02 (-0.02, 0.06)	0.25	-0.02 (-0.10, 0.06)	0.60	0.96 (0.65, 1.28)	<0.001	0.24 (0.13, 0.36)	<0.001
Upper muscular strength								
Handgrip strength (kg)								

Unadjusted	-0.03 (-0.05, -0.01)	0.001	0.03 (-0.01, 0.07)	0.14	0.31 (0.13, 0.49)	0.001	0.04 (0.00, 0.07)	0.050
Adjusted model 1[3]	-0.02 (-0.05, -0.00)	0.031	0.05 (0.01, 0.09)	0.011	0.25 (0.07, 0.42)	0.006	0.05 (0.02, 0.09)	0.005
Adjusted model 2[4]	-0.01 (-0.04, 0.01)	0.25	0.03 (-0.01, 0.08)	0.16	0.20 (0.01, 0.39)	0.042	0.07 (-0.00, 0.13)	0.061
Lower muscular strength								
Standing long jump (cm)								
Unadjusted	-0.04 (-0.21, 0.13)	0.66	0.47 (0.09, 0.85)	0.017	3.26 (1.54, 4.97)	<0.001	0.50 (0.16, 0.83)	0.004
Adjusted model 1[3]	-0.08 (-0.30, 0.15)	0.51	0.41 (0.01, 0.82)	0.047	2.89 (1.14, 4.64)	0.001	0.44 (0.08, 0.80)	0.016
Adjusted model 2[4]	0.09 (-0.15, 0.33)	0.48	0.11 (-0.35, 0.58)	0.64	3.17 (1.25, 5.10)	0.001	1.23 (0.55, 1.90)	<0.001
Motor fitness								
4x10 m shuttle run (sec)								
Unadjusted	0.01 (-0.01, 0.04)	0.26	-0.06 (-0.11, -0.01)	0.011	-0.63 (-0.85, -0.42)	<0.001	-0.07 (-0.12, -0.03)	0.001
Adjusted model 1[3]	0.02 (-0.01, 0.05)	0.15	-0.06 (-0.11, -0.01)	0.022	-0.62 (-0.84, -0.41)	<0.001	-0.07 (-0.12, -0.03)	0.002
Adjusted model 2[4]	-0.01 (-0.04, 0.02)	0.38	0.01 (-0.04, 0.07)	0.64	-0.67 (-0.90, -0.43)	<0.001	-0.16 (-0.25, -0.08)	<0.001

[1] Classified according to Chandler et al.[23].

[2] SB, sedentary behavior; MPA, moderate-intensity physical activity; VPA, vigorous-intensity physical activity; MVPA, moderate-to-vigorous physical activity; FM, fat mass; FFMI, fat-free mass index; FMI, fat mass index; WC, waist circumference.

[3] Adjusted for maternal BMI, maternal educational attainment (university degree/ no university degree), paternal BMI, paternal educational attainment (university degree/no university degree), child's sex and age at measurement, and awake wearing time. In addition, WC was adjusted for height.

[4] For SB and MPA model 2 was adjusted as for model 1 and for VPA. For VPA, and MVPA, model 2 was adjusted as for model 1 and for SB.

Table 4. Isotemporal substitution of physical activities per five minutes change.

	SB		LPA		MPA		VPA	
	b (95% CI)	p	b (95% CI)	p	b (95% CI)	p	b (95% CI)	p
FFMI (kg/m^2)								
Model A (replace SB)	Dropped		-0.01 (-0.04, 0.02)	0.42	0.01 (-0.02, 0.04)	0.58	0.17 (0.04, 0.30)	0.012
Model B (replace LPA)	0.01 (-0.02, 0.04)	0.42	Dropped		0.02 (-0.03, 0.08)	0.45	0.18 (0.05, 0.30)	0.005
Model C (replace MPA)	-0.01 (-0.04, 0.02)	0.58	-0.02 (-0.08, 0.03)	0.45	Dropped		0.16 (0.01, 0.31)	0.041
Model D (replace VPA)	-0.17 (-0.30, -0.04)	0.012	-0.18 (-0.31, -0.05)	0.005	-0.16 (-0.31, -0.01)	0.040	Dropped	
20m shuttle run (laps)								
Model A (replace SB)	Dropped		-0.05 (-0.12, 0.03)	0.20	0.01 (-0.08, 0.10)	0.84	0.87 (0.53, 1.22)	<0.001
Model B (replace LPA)	0.05 (-0.03, 0.12)	0.20	Dropped		0.06 (-0.08, 0.20)	0.43	0.92 (0.59, 1.25)	<0.001
Model C (replace MPA)	-0.01 (-0.10, 0.08)	0.85	-0.06 (-0.20, 0.08)	0.44	Dropped		0.86 (0.47, 1.26)	<0.001
Model D (replace VPA)	-0.87 (-1.21, -0.53)	<0.001	-0.92 (-1.25, -0.59)	<0.001	-0.86 (-1.26, 0.46)	<0.001	Dropped	
Handgrip strength (kg)								
Model A (replace SB)	Dropped		-0.00 (-0.05, 0.04)	0.96	0.03 (-0.02, 0.09)	0.22	0.17 (-0.04, 0.38)	0.11
Model B (replace LPA)	0.00 (-0.04, 0.05)	0.96	Dropped		0.04 (-0.05, 0.12)	0.42	0.17 (-0.03, 0.38)	0.092
Model C (replace MPA)	-0.03 (-0.09, 0.02)	0.22	-0.04 (-0.12, 0.05)	0.42	Dropped		0.14 (-0.10, 0.38)	0.26
Model D (replace VPA)	-0.17 (-0.38, 0.04)	0.10	-0.18 (-0.38, 0.03)	0.089	-0.14 (-0.38, 0.10)	0.26	Dropped	
Standing long jump (cm)								
Model A (replace SB)	Dropped		-0.46 (-0.90, -0.02)	0.041	0.40 (-0.14, 0.94)	0.14	2.09 (0.01, 4.17)	0.049
Model B (replace LPA)	0.46 (0.02, 0.90)	0.041	Dropped		0.86 (0.00, 1.71)	0.049	2.55 (0.53, 4.56)	0.013
Model C (replace MPA)	-0.40 (-0.94, 0.14)	0.14	-0.86 (-1.71, -0.01)	0.048	Dropped		1.68 (-0.74, 4.10)	0.17
Model D (replace VPA)	-2.12 (-4.20, -0.04)	0.046	-2.58 (-4.59, -0.56)	0.012	-1.72 (-4.14, 0.69)	0.16	Dropped	
4x10m shuttle run (sec)								
Model A (replace SB)	Dropped		0.03 (-0.03, 0.08)	0.37	-0.00 (-0.07, 0.07)	0.95	-0.62 (-0.88, -0.36)	<0.001
Model B (replace LPA)	-0.03 (-0.08, 0.03)	0.37	Dropped		-0.03 (-0.13, 0.08)	0.62	-0.65 (-0.90, -0.40)	<0.001
Model C (replace MPA)	0.00 (-0.07, 0.07)	0.95	0.03 (-0.08, 0.13)	0.62	Dropped		-0.62 (-0.92, -0.32)	<0.001
Model D (replace VPA)	0.62 (0.36, 0.88)	<0.001	0.65 (0.40, 0.90)	<0.001	0.62 (0.32, 0.92)	<0.001	Dropped	

SB, sedentary behavior; LPA, light-intensity physical activity; MPA, moderate-intensity physical activity; VPA, vigorous-intensity physical activity; FFMI, fat-free mass index

Model A. With variables: LPA (min/day), MPA (min/day), VPA (min/day), awake wearing time, maternal BMI, maternal education, paternal BMI, paternal education, child's sex and age

Model B. With variables: SB (min/day), MPA (min/day), VPA (min/day), awake wearing time, maternal BMI, maternal education, paternal BMI, paternal education, child's sex and age

Model C. With variables: SB (min/day), LPA (min/day), VPA (min/day), awake wearing time, maternal BMI, maternal education, paternal BMI, paternal education, child's sex and age

Model D. With variables: SB (min/day), LPA (min/day), MPA (min/day), awake wearing time, maternal BMI, maternal education, paternal BMI, paternal education, child's sex and age

IV

LONGITUDINAL PHYSICAL ACTIVITY, BODY COMPOSITION AND PHYSICAL FITNESS IN PRESCHOOLERS

by

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