Ada Kristine Ofrim Nilsen // Physical activity among preschoolers

DISSERTATION FROM THE
NORWEGIAN SCHOOL OF
SPORT SCIENCES
2020

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Cross-sectional and prospective findings from the Sogn og Fjordane Preschool Physical Activity Study

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SUMMARY – ENGLISH

Introduction: Physical activity (PA) during early childhood is of great importance for children's health and development. As PA levels are known to decrease over time in school-aged children and adolescents, the preschool years have been highlighted as a crucial period for establishing adequate levels of PA. However, evidence suggests that many preschoolers are not sufficiently physically active. Before interventions aiming to increase PA can be initiated, observational research is required to identify factors influencing PA behaviours among preschoolers, including how PA varies and develops by individual characteristics such as sex, age, and fundamental motor skills (FMS), and varies by environmental factors, such as season and setting. Moreover, to understand prevalence rates of PA across borders, large studies are needed from a wide range of countries. Currently, no large-scale study has determined PA objectively in Norwegian preschoolers.

Aims: The aims of this thesis was to increase knowledge about PA levels among Norwegian preschoolers; to investigate cross-sectional associations between PA and sex, age, season, setting (i.e., preschool hours vs. time out of care) and FMS; and investigate bi-directional, prospective associations between PA and FMS development.

Participants and methods: This thesis was based on the 'Sogn og Fjordane Preschool Physical Activity Study' (PRESPAS) conducted in 2015-2016 (cross-sectional data) and 2017 (longitudinal data), and included in total 68 preschools and 1308 children aged 2.7-6.5 years (at baseline). For the cross-sectional sample, PA and FMS were measured at one time point (2015-2016). A subsample of children (n=376) participated in three repeated measurements of PA at baseline and in one follow-up measurement (2017). For this longitudinal sample, FMS were measured one time at baseline and one time at follow-up. PA was assessed objectively by ActiGraph GT3X+ accelerometers over 14 days for each monitoring period. FMS were evaluated through a test battery inspired by the 'Test of Gross Motor Development 3' and the 'Preschooler Gross Motor Quality Scale'.

Main results: Overall, children had a mean total PA (SD) of 754 (201) counts per minute. Boys were consistently more active and less sedentary than girls, and PA increased with age for both sexes – although boys exhibited a greater increase than girls in moderate-to-vigorous PA (MVPA) over time. MVPA varied by season, being highest during spring and summer. Boys spent more time in MVPA during preschool hours than during time out-of-care. Boys and the oldest 50% of the children had relatively higher MVPA levels during preschool hours than girls and the younger children. The PA intensity profile associated with FMS was characterised by vigorous intensities, and the strongest association was found for FMS within the locomotor domain. Baseline MVPA predicted improved FMS two years later, but baseline FMS did not predict future PA levels.

Conclusions: Norwegian preschoolers have similar overall PA levels as to the international mean, with a potential to increase MVPA, and thus, achievement of PA guidelines. Our results show that the preschool arena is important for children's MVPA. However, our findings indicate that this environment most successfully stimulates boys, older children, and highly active children. The results further suggest that young children should spend time in MVPA to improve their FMS. It is, therefore, essential that PA programmes and social and physical environments, including preschools, are suited to provide movement opportunities for all children to increase their PA levels and improve their FMS.

Key words: accelerometer, associations, behaviour, children, development, epidemiology, fundamental motor skills, kindergarten, motor competence, physical activity, prediction, preschoolers, public health, reciprocal relationships.

SUMMARY – NORWEGIAN

Introduksjon: Tilstrekkelig fysisk aktivitet i tidlige barneår er viktig for barns helse og utvikling. Det er kjent at barns aktivitetsnivå reduseres med økende alder fra skolestart. På bakgrunn av dette fremheves barnehageårene som en sentral periode for etablering av gode aktivitetsvaner. Likevel viser forskning at mange barnehagebarn ikke er tilstrekkelig fysisk aktive. Før intervensjoner med mål om å fremme fysisk aktivitet kan igangsettes, må faktorer assosiert med fysisk aktivitet identifiseres gjennom observasjonelle studier. Kunnskap om faktorer assosiert med fysisk aktivitet blant barnehagebarn – eksempelvis; hvordan fysisk aktivitet varierer med individuelle karakteristikker, slik som kjønn, alder og motoriske ferdigheter, og med faktorer i miljøet rundt oss, slik som sesong og setting – danner grunnlag for målrettede tiltak. Videre fremskaffer større kartleggingsstudier verdifull kunnskap om hvordan barns aktivitetsnivå varierer mellom ulike land, miljø og kulturer. Dette er den første stor-skala kartleggingen av barnehagebarn sitt fysiske aktivitetsnivå i Norge.

Målsetninger: De overordnede målene i dette doktorgradsarbeidet var å øke kunnskapen om norske barnehagebarn sitt fysiske aktivitetsnivå, å undersøke tverrsnittassosiasjoner mellom fysisk aktivitet og kjønn, alder, sesong, setting (dvs., barnehagetid versus tid utenfor barnehagen) og motoriske ferdigheter, og å undersøke bi-direksjonale, prospektive assosiasjoner mellom nivå av fysisk aktivitet og utvikling av motoriske ferdigheter.

Deltakere og metoder: Denne avhandlingen er basert på forskningsprosjektet 'Sogn og Fjordane Preschool Physical Activity Study' (PRESPAS). Datainnsamlingen ble gjennomført i barnehageåret 2015-2016 (tverrsnittsdata) og i 2017 (longitudinelle data). Totalt deltok 1308 barn (alder: 2.7-6.5 år) fra 68 barnehager i prosjektet. For deltakerne i tverrsnittutvalget ble fysisk aktivitet og motorikk målt på ett tidspunkt (2015-2016). For oppfølgingsutvalget (n=376 barn) ble fysisk aktivitet målt tre ganger i løpet av barnehageåret 2015-2016 (baseline) og én gang høsten 2017 (follow-up). For oppfølgingsutvalget ble motorikk vurdert én gang på baseline og én gang på follow-up. Fysisk aktivitet ble målt objektivt ved hjelp av akselerometere (ActiGraph GT3X+) over 14 dager hver registreringsperiode. Motorikk ble vurdert gjennom et testbatteri inspirert av 'Test of Gross Motor Development 3' og 'Preschooler Gross Motor Quality Scale'.

Hovedfunn: Totalt hadde barna et gjennomsnittlig (standard avvik) aktivitetsnivå på 754 (201) «tellinger per minutt». Gutter var gjennomgående mer fysisk aktive og hadde mindre stillesittende tid sammenliknet med jenter, og fysisk aktivitet økte med alder for begge kjønn. Sammenliknet med jenter hadde gutter en relativt større økning i fysisk aktivitet av moderat til høy intensitet med økende alder. Aktivitet av moderat til høy intensitet varierte med sesong, med høyest nivå om våren og sommeren. Barna hadde mer tid i moderat til høy intensitet i barnehagetiden sammenliknet med tid utenfor barnehagen. Gutter og de 50% eldste barna i utvalget hadde relativt sett høyere aktivitetsnivå i barnehagetiden sammenliknet med jenter og de yngre barna. Intensitetsprofilen assosiert med motoriske ferdigheter var kjennetegnet av høy intensitet, og de sterkeste sammenhengene ble funnet for forflytningsferdigheter. Fysisk aktivitet av moderat til høy intensitet i barnehagealder predikerte økt motorisk ferdighetsnivå to år senere, men motorisk ferdighetsnivå i barnehagealder predikerte ikke fremtidig aktivitetsnivå.

Konklusjoner: Det fysiske aktivitetsnivået til norske barnehagebarn virker å være tilsvarende det internasjonale gjennomsnittet. Våre resultater viser at barnehagen er en viktig arena for fysisk aktivitet, men at disse settingene ser ut til å stimulere gutter og de eldste barna i større grad enn jenter og yngre barn. Resultatene viser videre at barn i barnehagealder bør være fysisk aktive i høyere intensiteter for å utvikle motoriske ferdigheter. Det er derfor viktig at det sosiale- og fysiske miljøet i barnehagen tilrettelegges slik at alle barn har mulighet til å delta i fysiske aktiviteter og til å utfordre seg motorisk.

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Sogndal, 1st of December 2019

Ada Kristine Ofrim Nilsen

LIST OF MANUSCRIPTS

This PhD thesis is based on the results from the following four manuscripts:

MANUSCRIPT I:

Nilsen, AKO; Anderssen; SA; Ylvisaaker, E; Johannessen, K; Aadland, E. *Physical activity among Norwegian preschoolers varies by sex, age, and season*. Scand J Med Sci Sports. 2019:29 (6);862-873. DOI: 10.1111/sms.13405.

MANUSCRIPT II:

Nilsen, AKO; Anderssen; SA, Resaland, GK; Johannessen, K; Ylvisaaker, E; Aadland, E. *Boys, older children, and highly active children benefit most from the preschool arena regarding moderate-to-vigorous physical activity: a cross-sectional study of Norwegian preschoolers.* Prev Med Rep. 2019;14:100837. DOI: 10.1016/j.pmedr.2019.100837.

MANUSCRIPT III:

Nilsen, AKO; Anderssen; SA, Loftesnes, JM; Johannessen, K; Ylvisaaker, E; Aadland, E. *The multivariate physical activity signature associated with gross motor skills in pre-schoolers*. J Sports Sci. 2019:1-9. DOI: 10.1080/02640414.2019.1694128.

MANUSCRIPT IV:

Nilsen, AKO; Anderssen, SA; Johannessen, K; Aadland, KN; Ylvisaaker, E; Loftesnes, JM; Aadland, E. *Bi-directional prospective associations between objectively measured physical activity and fundamental motor skills in children: a two-year follow-up.* Int J Behav Nutr Phys Act. 2020;17(1):1. DOI: 10.1186/s12966-019-0902-6.

ABBREVIATIONS

BMI	Body mass index
CI	Confidence interval
cpm	Counts per minute
CVD	Cardiovascular disease
ECEC	Early Childhood Education and Care
FMS	Fundamental motor skills
ICAD	International Children’s Acceleromerty Database
ICC	Intra-class correlation
IRR	Inter-rater reliability
LPA	Light physical activity
M-ABC	Movement Assessment Battery for Children
MET	Metabolic equivalent
Min	Minutes
MPA	Moderate physical activity
MVPA	Moderate-to-vigorous physical activity
NSD	Norwegian Centre for Research Data
PA	Physical activity
PGMQ	Preschooler Gross Motor Quality Scale
PLS	Partial least squares
PRESPAS	Sogn og Fjordane Preschool Physical Activity Study
SES	Socio-economic status
SED	Sedentary behaviour
SD	Standard deviation
SR	Selectivity ratio
TGMD	Test of gross motor development
TPA	Total physical activity [cpm]
VPA	Vigorous physical activity
WHO	World health organization

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1. BACKGROUND

1.1 INTRODUCTION

Giving every child a good start in life should be of high priority to address social inequality and improve population health, laying the foundation for equitable development of human capital and life opportunities (1, 2). The preschool period (understood as children aged 3-6 years who have not yet started school) is a time of rapid growth and maturation, including significant cognitive, physical and social development (3), as well as the formation of behaviour patterns (4). Thus, these early childhood years are critical for children's future health and well-being (4).

There is overwhelming evidence showing that physical activity (PA) is favourably associated with physical health, including reduced risk of non-communicable diseases in adults (5, 6) and reduced risk of obesity and cardio-metabolic risk factors in children (7-9). There is also strong evidence that PA is favourably related to brain health and cognition in adults (10, 11), and emerging evidence of an association with brain health, cognition, and learning outcomes in children (12-14). Thus, sufficient PA levels are important for health and development throughout life.

Behavioural patterns related to PA and sedentary behaviour (SED) are typically established during early childhood, and evidence suggests that these behaviours to some extent track over time (15, 16). A sufficient level of PA at an early age, therefore, provides a foundation for children's future health and development. Since PA levels are known to decrease over time in school-aged children and adolescents (17, 18), the preschool years have been highlighted as a crucial period for establishing optimal levels of PA (19). It is, therefore, worrying that many preschoolers appear to be insufficiently physically active (20-24).

Although the proportion of children attending preschool varies across the globe, the preschool setting are suited to reach many children, especially in Norway where 97% of 3–5-year-olds attend preschool for an average of 33 hours per week (25, 26). Consequently, this environment have great potential to influence on children's behaviour, including participation in PA. Since interventions before school age are the most cost-effective ones (27, 28), there is a need for broad, evidence based programmes to ensure sufficient levels of PA in early childhood. However, before targeted interventions can be developed in order to increase levels of PA in young children, observational research need to establish knowledge about levels of PA among preschool-aged children across areas with different cultural, social, and physical environments. Further, there's a need to identify factors influencing PA behaviours, e.g., how PA varies and develops by individual characteristics such as sex, age, and physical abilities, and varies by environmental factors, such as season, setting, and time of week.

With regard to physical abilities influencing PA, fundamental motor skills (FMS), is considered an important determinant throughout childhood and adolescence (29). Children develop their FMS through engagement in PA from an early age (30), and an adequate level of FMS is necessary to move and control the body to enable participation in physically active play (30). Thus, the preschool years is considered vital for both establishing sufficient PA levels (31, 32) and for FMS development (33).

To understand prevalence rates of PA in preschool populations, large studies are needed from a wide range of countries. Currently, no large-scale study has determined PA objectively in Norwegian preschoolers. The aim of this thesis was, therefore, to increase knowledge about PA levels among Norwegian preschoolers, and to investigate cross-sectional and longitudinal associations between PA and sex, age, season, setting (i.e., PA during preschool hours versus time out-of-care), and FMS.

1.2 DEFINITIONS AND CLARIFICATION OF CONCEPTS

PHYSICAL ACTIVITY AND SEDENTARY BEHAVIOUR

PA is a multidimensional behaviour that can be defined as *'[…]any bodily movement resulting from contractions of skeletal muscle that result in an increase in energy expenditure above resting levels'* (34). PA varies over time within individuals (35, 36), and consists of several dimensions, including intensity, frequency, and duration, resulting in the total volume of PA. Two additional dimensions of PA is the type of activity and the context in which the PA takes place, the latter often referred to as domain. The volume of PA is related to energy expenditure (34), which can be expressed as metabolic equivalent of task (MET)(37). One MET in adults is normally defined as the amount of oxygen consumed while resting, and is equal to 3.5 mL O_2 per kg body weight × minutes (38). MET thresholds defining light (LPA) (1.5-2.9 METs), moderate (MPA) (3.0-5.9 METs), and vigorous (VPA) ($\geq$ 6.0 METs) PA is one approach used to categorise PA intensities, although the observed MET values are different in children as compared to adults because of higher basal metabolic rates per unit body mass (39, 40), and because children have disproportionately higher energy expenditure relative to body mass when performing PA (41).

Related terms to PA include 'sedentary behaviour' (SED) and 'physical inactivity'. SED is at the lower end of the intensity spectrum, often defined as any waking behaviour characterised by an energy expenditure of <1.5 METs while in a sitting, reclining, or lying posture (42), while physical inactivity refers to a failure to achieve the guideline amount of PA (42). These terms are therefore not equivalent.

FUNDAMENTAL MOTOR SKILLS

Motor development concerns the sequential, age-related, and continuous change in motor behaviour over the life span (43). In this thesis, 'Fundamental motor skills' (FMS) is applied as a global term to reflect various terminologies used in the literature (e.g., motor competence, motor proficiency, gross motor skills, motor performance, fundamental movement skills, motor coordination, and motor ability) to describe the quality of goal-directed movements involving coordination and control of the human body.

FMS develops from the early phases of infancy to more complicated movements and can be defined as the 'building blocks' that leads to more specialised and complex movements, which in turn enables participation in physically active play, sports, and other organised and non-organised physical activities (44, 45). Although the type of skills defining FMS vary in the literature, FMS are often categorised into three domains: locomotor (e.g., running and hopping), object control (e.g., catching and throwing), and balance/stability skills (e.g., standing on one foot and walking on line) (44). The preschool period is characterised by development of FMS within these three domains.

FMS are closely related to ‘physical fitness’ (46), which is a set of attributes that people have or achieve relevant for health and/or for sports performance, such as cardiorespiratory fitness, muscular fitness, and mobility (34). Thus, varying aspects of physical fitness are required to perform FMS’ (44), and because physical fitness is measured by performing movements, elements of FMS will always be included in the fitness performance (47).

1.3 PHYSICAL ACTIVITY, HEALTH, AND DEVELOPMENT

'Health' is historically viewed as the absence of disease or premature mortality; though, the World Health Organization (WHO) defines health as *'[…]a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity'* (48). Today, most agree that definitions of health should incorporate both disease prevention and health promotion, with the latter term to a greater degree embracing positive aspects of health and well-being. Furthermore, children's health can be defined as *'[…]the extent to which individual children or groups of children are able or enabled to (a) develop and realize their potential, (b) satisfy their needs, and (c) develop the capacities that allow them to interact successfully with their biological, physical, and social environments'* (49). This definition is found meaningful for the present thesis, as it captures the central aspects of child development and well-being.

The major causes of death and disability globally are non-communicable diseases such as heart disease and stroke, cancer, chronic respiratory disease, obesity, and diabetes mellitus (50). Of these conditions, cardiovascular disease (CVD) is the leading cause of mortality worldwide (50, 51). Importantly, risk factors for CVDs – including obesity and high blood pressure, and high blood lipid and lipoprotein levels – have been found to cluster in children (7) and to track from childhood to adulthood (52). Thus, although children do not establish CVDs, tracking of CVD risk factors from childhood to adulthood indicates that cardio metabolic diseases have their origins early in life (53, 54). Because risk factors track and emerge over time, the large increase in childhood obesity observed worldwide (55) is recognised by the WHO as one of the most serious public health challenges of the 21st century.

Socioeconomic inequality is another serious public health challenge related to non-communicable diseases. Such inequalities in health mean that individuals with higher levels of education and income live longer and have fewer health problems than those with less education and poorer economic circumstances (56). Social differences in health accrue at all ages, including in children (57). Thus, it is possible that inequalities in adult health may already be determined in childhood and may be further accentuated by socioeconomic inequalities in behaviour and educational attainment in childhood and adolescence (58).

PA plays a key role in prevention of most non-communicable diseases in adults (5, 6). In children, PA of moderate-to-vigorous intensity (MVPA) has been associated with reduced cardiovascular and metabolic risk (7-9, 59-63), including reduced risk of childhood obesity (64). Socio-economic status (SES) is further positively associated with PA in adults (65), and studies of adolescents provide evidence of a link between higher levels of PA and more advantageous socioeconomic background (66).

Associations between parental SES and children's PA levels are, however, inconsistent in studies addressing preschool populations (65, 67).

As PA is recognised as the least expensive and most effective means of preventing non-communicable diseases in adults (68, 69), discussions of the benefits of PA for children are often framed within the context of future physical health (69). However, the importance of PA for young children extends beyond physical health. There is solid evidence that PA favourably affects brain health and cognition in adults (10, 11). Moreover, there is a growing body of evidence of a favourable relationship between PA and psychological health and social well-being, FMS development and sports participation, and cognitive and academic performance in children (9, 32, 69-71). A focus on PA during the early years may change children's activity trajectory and increase the likelihood that they will be physically active throughout adolescence and into adulthood (15, 16), potentially with the consequence of reduced risk of chronic diseases related to physical inactivity.

1.4 ASSESSMENT OF PHYSICAL ACTIVITY

MEASURING PHYSICAL ACTIVITY IN CHILDREN

Accurate and precise measurements are important to determine PA levels and identify associations between PA and other health-related outcomes, monitoring of secular and longitudinal trends in behaviour, and evaluate the effectiveness of interventions. Thus, to draw meaningful conclusions, valid, reliable, and feasible measurement methods are needed (72). The complexity of PA behaviour makes it difficult to measure and no single method exists that can capture all sub-components of PA (73).

Traditionally, parent reports have been used to measure PA in young children, as self-reported measures are considered inappropriate for children under the age of 10 years (74). Subjective methods can provide useful information about the context and type of PA, but they are limited by biased reporting and low validity (75, 76). Especially relevant is bias associated with the reporter's memory and perception of the child's PA level, in addition to the influence of social norms and expectations of health-related behaviour (77) that can lead to overestimation of actual PA levels (72).

Another recognised method to measure PA in young children is direct observation. When using direct observation, a trained observer records PA behaviour for a predetermined period, and scores the PA according to specific codes that correspond to characteristics of the activity. Direct observation can provide good information of PA, including intensity, type, and context (both environmental and social) (74). The main disadvantage of direct observation systems is that both in-field training and assessment are very time consuming, making the method unsuitable for large study samples. Furthermore, regular inter-rater reliability tests to ensure high agreement among observers, are necessary to obtain high validity (74).

As a consequence of the limited reliability and validity of subjective measures – and the limited feasibility of direct observation – objective methods, especially accelerometry, has become widely used to assess PA in large study samples.

ACCELEROMETRY

When applied to the measurement of PA, an accelerometer measures the magnitude and total volume of movement as a function of time (78, 79). Several reviews have concluded that accelerometers provide an accurate, reliable, and practical objective measure of PA in children (80-83). The accelerometers from ActiGraph (LLC, Pensacola, Florida, USA) (84) are the most frequently used monitors in research, accounting for >50% of published studies by 2015 (85).

There are, however, several known methodological challenges related to the use of accelerometry in the assessment of PA (72).

Accelerometers measure accelerations of the body segment to which the monitor is attached (86), for ActiGraphs' this is normally the hip/waist or the wrist. There is an ongoing discussion concerning the placement of the monitor, as an accelerometer placed on the hip will not accurately assess movement of the arms, nor will it be able to accurately measure the added energy expenditure of carrying a load while moving or non-ambulatory activities that do not involve vertical movement of the trunk, such as cycling and swimming (78). For preschoolers, both wrist and hip placements have shown high potential to correctly classify PA intensity (87, 88), although it has been suggested that accuracy measures are greater when the accelerometer is placed on the hip than on the wrist (37).

The ActiGraph acceleration signal is filtered and pre-processed by the monitor to obtain 'raw' activity counts (reported in counts per minute [cpm]) (86) that are a unit-less, dimensionless outcome (78). Definitions of PA intensity are derived from calibration using energy expenditure or direct observation as the criterion, providing a cut point threshold that is identified by a specific count value (78). Cut point calibration studies for ActiGraph accelerometers in children have used a wide variety of methods, and many different cut points have been proposed in the literature, with an ongoing debate about which thresholds are most appropriate across age groups (72). Moreover, the selection of MET definitions of MVPA in children vary between studies calibrating cut points, with common definitions ranging from 3 to 4.6 METs (72). At a 4-MET intensity, recommended cpm ranged from 1400 to 3600 across studies (72). In addition, some calibration studies have recommended age-specific cut points (e.g., (89-93)), while others have used the same cut points across age groups (e.g., (94-98)). As the choice of MVPA cut points has a large impact on study comparability and PA prevalence rates (72), this lack of consensus is highly problematic.

In 2011, Trost and colleagues (99) published a validation study in 5 to 15 year-old children comparing five common cut points using maximum oxygen consumption (VO_2 peak) during 12 physical activities as the criterion measure. Trost et al. found that the Evenson cut points (97) showed the best classification of MVPA ($\geq$ 2296 cpm). Based on this finding, the Evenson cut points have been widely used in paediatric populations, including preschool populations (86).

The amount and intensity of PA and SED is obtained by classification of activity counts accumulated in specific time intervals called epochs (86). Traditionally, a 60-second epoch has been the most commonly used. However, as children have a rather sporadic PA pattern, with bouts of PA generally lasting <10 seconds (100-103), shorter epochs have been recommended to more accurately capture PA in younger populations (72). Summation of PA over longer epochs leads to loss of time spent in the lower and higher end of the intensity spectrum (i.e., overestimation of LPA and underestimation of SED and VPA) (101-105).

When processing accelerometer data, the definition of wear time is relevant, because non-compliance with data collection protocols is common. Aadland et al. examined how many days were needed to obtain an intraclass correlation coefficient (ICC) of 0.80 with different hours per day wear-time criteria in a sample of preschoolers, and they found that 8 hours per day over 3-5 days provided the same information as 10 hours of registration per day (ICC: 0.87 for MVPA) (35). Furthermore, a minimum of four valid days has been suggested as the inclusion criteria to provide a stable measure of habitual PA (86, 106). However, due to the considerable week-by-week variability observed when measuring PA by accelerometers in preschool-aged children (35), a longer registration period (>7 days) would increase the reliability of the accelerometer measurements (35) and, thus, increase the validity of the study conclusions.

1.5 ASSESSMENT OF FUNDAMENTAL MOTOR SKILLS

Proficiency in FMS has gained credence in the last decades as an important correlate of PA and other health related outcomes in children (29), such as weight status and physical fitness (46). Such evidence has led to an increased focus on assessment methods used to quantify FMS in normally developing children.

FMS assessments are commonly used as evaluation tools for physical education, motor development, and evaluation of performance (107), and many different assessment tools are available. The tools may vary in the type (product- or process-oriented) and number of skills measured, ease of administration and time use, assessment context, scoring procedures, and the participant and researcher burden (108). The choice of method should be determined primarily by the study aim and target group (e.g., whether the aim is to identify children with motor deficits, categorize or rank children in a sample based on skill level, evaluate the effects of interventions aiming to improve FMS, or predict future FMS level) (108).

It is common to evaluate FMS by measuring specific skills through many sub-tests (items) that jointly provides information about overall or domain-specific FMS (109). It is difficult, however, to determine the most representative skills to target because skills that some might consider ‘fundamental’, may be different in other groups of children or in other contexts (109). Skills considered FMS have often been tied to skills that require practice and training and, as such, are integrated into common sports, such as kicking and running as a part of soccer. Yet, there is also a degree of cultural appropriateness when defining FMS, as different sports, games, and physical activities are popular in different countries (e.g., soccer in Europe and baseball in the USA) (109). Thus, the most relevant skills to assess might differ across contexts.

Objectives for studying FMS include describing and understanding the process and product of movement patterns (107); thus, FMS tools can be broadly categorised into two types: process- and product-oriented tests. A product-oriented test evaluates *the outcome,* or result, of a movement, which is typically identified as a quantitative score (e.g., speed, distance, or number of successful attempts) (107). Examples of product-oriented tests frequently used in the literature are the ‘Movement Assessment Battery for Children-2’ (M-ABC 2 (110)) developed in the UK, the ‘Motoriktest für Vier bis Sechjärige Kinder’ (MOT 4-6 (111)), and the ‘Köperkoordinationstest für Kinder’ (KTK (112)) (both German origin). In contrast, a process-oriented test evaluates *how* a movement is performed and is based on a qualitative evaluation and comparison of a child’s performance to predetermined criteria (that often can be quantified) (108). Examples of commonly used tests with process-oriented evaluation are the American test battery ‘Test of Gross Motor Development-3’ (TGMD-3)(113), the ‘Peabody Developmental Motor Scales-2’ (PDMS-2 (114)), and the Australian resource ‘Get Skilled; Get Active’ (115).

FMS tests differ in their complexity of administration due to the number of items included and number of performance criteria for each item, and it is debated whether it is possible to fully operationalise and measure general underlying motor abilities. In addition, FMS assessment tools do not always discriminate well between FMS and physical fitness, as it is difficult, if not impossible, to obtain a pure measure of either FMS or fitness (116), and thus to find the independent contributions of each phenomenons to the outcomes of interest (116). Nevertheless, it can be argued that measuring physical fitness is different to measuring FMS – especially when using process-oriented test batteries (i.e., quality assessment) – because fitness tests primarily demand muscular strength (force-generating capacity) or endurance, flexibility, and/or aerobic performance, in contrast to coordinative abilities.

As there is no gold standard for FMS assessment in young children, Cools and colleagues evaluated seven different FMS assessment tools used among preschoolers and compared the tests’ content and validity, and the reliability between the tests (108). Both process- and product-oriented test batteries were included in the evaluation. In general, the reported internal consistency and inter-rater reliability were high for all tests. However, with regards to validity, inter-test comparisons showed only moderate correlations (108). This is in line with more recent comparisons of process- and product-oriented tests (107, 117, 118), where different tools provide deviating information about FMS, which makes it challenging to conduct cross-study comparisons when different methods are used.

One of the most widely recognised tests for FMS evaluation, the TGMD, was designed for children aged 3-10 years. The third version (TGMD-3) is based on observation of children's movements across 13 tasks within the two domains: locomotion (run, skip, slide, gallop, hop, and horizontal jump) and ball/object control (hereafter referred to as 'object control') (overhand throw, underhand throw, catch, dribble, kick, one-hand strike, and two-hand strike) (113). The TGMD-3, and its prior versions, measures gross movement performance based on qualitative aspects of motor skills, and is widely used in preschoolers (117, 119). The TGMD can be categorised as both a process- and product-oriented test, as it refers to both criteria and normative scores (108).

According to the author, the TGMD-3 can be used to identify children who are significantly behind their peers in gross motor performance, to plan programmes to improve their skills, and to assess changes due to increasing age or following an intervention (113). The age range covers the period in which the most dramatic changes in a child's FMS development occur (113), which makes this battery appropriate for following children over time. A limitation of the TGMD-3 is that it was developed in USA and contains particular movement tasks that are less culturally relevant in European countries (e.g., the baseball strike and bouncing ball). Thus, as highlighted by Cools et al., the TGMD needs adaptation to fit a European context (108). Furthermore, the test battery does not contain balance tasks, which is a limitation, as balance skills is considered one of three domains of FMS (44). Therefore, the TGMD-3 could be combined with other instruments that provide similar scoring procedures to assess balance skills, such as the Preschooler Gross Motor Quality Scale (PGMQS, (120)).

1.6 PHYSICAL ACTIVITY BEHAVIOUR IN PRESCHOOLERS

PHYSICAL ACTIVITY RECCOMENDATIONS

Among preschool-aged children PA mainly takes the form of basic movements, expressed through physically active play or through structured activities (i.e., planned, regularly scheduled activities) such as ball games, swimming lessons, organised hikes, and simplified dance or gymnastics movements (78). A common characteristic of PA in childhood is the sporadic and intermittent pattern (78). The population of children under school age is the most active (17), but their PA rarely occurs over a continuous period of time. Rather, children's PA consists of short bursts of MVPA punctuated by periods of LPA or SED (121).

WHO recommends that children from the age of three engage in a variety of physical activities of which at least 60 minutes is MVPA every day (122, 123), which is also the recommended level in the Nordic countries (124, 125). Until recently, Australia, the UK, and Canada were recommending that preschoolers participate in 180 minutes per day of total (non-SED) PA (TPA) (126-128). In the USA, national guidelines state that preschool-aged children *'[…]should be physically active throughout the day'* and that *'[…]a reasonable target may be 3 hours per day of activity of all intensities'* (129). However, there is growing evidence that MVPA is associated with greater health benefits than lower intensity PA (7-9, 59-62). Therefore, the level of compliance with the 60 min of MVPA per day recommendation might be more relevant than the TPA guidelines. In response to new evidence, Canada, Australia and the UK have recently updated their PA guidelines for the early years to include a minimum of 60 minutes of MVPA in the 180 minutes of TPA (130-132).

LEVELS OF PHYSICAL ACTIVITY

To inform government policy and community initiatives, it is important to accurately quantify preschoolers' participation in MVPA, both to determine the necessity of a focus on the preschool age group (i.e., if most preschoolers are highly active, they would be less of a priority than older children and adolescents) and to monitor the effectiveness of strategic initiatives that aim to increase MVPA. Consequently, levels of PA among young children have been widely examined over the last decade (20-24, 133-135).

While most studies suggest that nearly all preschoolers achieve 180 minutes of total PA per day (20-23, 134, 135), mainly due to a large proportion of time spent in LPA, many preschoolers spend insufficient time in MVPA (20, 23, 134). Based on an examination of a nationally representative sample of Canadian children, Colley et al. report that just 14% of five-year-olds spent ≥ 60 minutes in MVPA per day (MVPA ≥1150 cpm) (134). In contrast, a large study by Ruiz et al. (N=1131) found that American preschoolers spent 90 minutes per day in MVPA (1680 cpm) on average, which is equal to 13% of the day. Furthermore, Hnatiuk et al. reported in their review of n=37 different study samples (N=40 studies) that the proportion of time spent in MVPA varied greatly among studies, ranging from 2 to 41% (23). Bornstein et al. also found great variability in their systematic review and meta-analysis of N=6309 children (aged 3-5 years) in 29 studies, with results ranging from 40 to 100 minutes of MVPA per day (20). On average children spent 43 minutes (95% CI: 29–57) in MVPA per day across all the studies included, which is equal to 5.5 % (95% CI: 3.7-7.2 %) of their daily time in this intensity range (20). In the studies using the ActiGraph accelerometers included in the study by Bornstein et al. (76%), children spent 79 minutes (95 % CI: 51–107) per day in MVPA (20).

Due to differences in accelerometer data processing methods, there is a wide variability in reported accelerometer-derived MVPA levels of preschool-aged children, making comparison of prevalence rates across studies challenging. Despite this variability, studies included in the analysis by Bornstein et al. using the ActiGraph accelerometers reported an average TPA of 714 cpm (95% CI: 678–751), which is a comparable estimate for TPA, regardless of intensity (20). Only one, recently published, study has made a cross-national comparison of the proportion of preschool-aged children meeting guideline levels of MVPA using a standardised method of processing accelerometry data (133). This study, by Dias et al., is based on a sample of N=1052 children (mean age 3.9, 51% girls) from six studies included in the International Children's Accelerometry Database (ICAD). In the countries represented (the UK, Switzerland, Belgium, and the USA), 79% of the children met the daily guidelines of ≥ 60 minutes of MVPA (MVPA ≥1680 cpm). This percentage varied between the countries, with the lowest observed in Belgium (50%), and the highest observed in the USA (89%) (133).

To our knowledge, four previous studies have examined objectively measured PA in Norwegian preschoolers (35, 136-138). Kippe and Lagestad found that 84% of the children (N=244, aged 4-6 years) achieved the MVPA guideline (MVPA ≥ 2000 cpm) (137). Andersen et al. measured PA during preschool hours in a sample of N=111 children (aged 3-4 years), and found that 32% of the girls and 67% of the boys reached 60 minutes MVPA per day (MVPA ≥ 2120 cpm) (136). In the investigation by Dønnestad et al. (138) 56% of the children (N=92, aged 3-6 years) met the MVPA guideline during preschool hours (MVPA ≥ 2000 cpm), and Aadland and Johannessen found that 55% of their study sample of preschoolers (N=91, aged 3-5 years) achieved 60 minutes of MVPA per day (MVPA ≥ 2296 cpm) (35). However, these studies have small sample sizes (N=91-244), some only measured PA during preschool hours (in contrast to a whole-day approach), and all the data were collected within one season, which limits the generalisability to other samples and seasons. Currently, no large-scale study has objectively explored PA among Norwegian preschoolers, thus more research on this population is warranted.

PHYSICAL ACTIVITY BY SEX AND AGE

It is well documented that boys are generally more active than girls (17); and although one systematic review concluded there was no sex differences in PA among preschool-aged children (139), most evidence suggests sex differences are present in in this age group (19, 20, 67, 70, 133, 140, 141). However, sex differences in PA do seem to depend on growth and development. This dependence is illustrated by differing findings for adolescent boys and girls when using biological versus chronological age (142) and by the fact that differences in PA between boys and girls do not seem to be present in two-year-old children (143). Thus, it could be hypothesised that sex differences in PA increases with age, and that differences between boys' and girls' PA levels are less evident in preschool populations than among older children. Furthermore, children's MVPA levels are known to decrease over time after the age of five (17). This is accompanied by a progressive increase in SED and LPA (17). Several studies (144, 145) have found that younger preschoolers (3-4 years old) tend to be more physically active than older preschoolers (5-6 years old), though many studies indicate an opposite trend (133, 146-148). Thus, more research is needed to determine how PA develops over time within the preschool age range, and whether this development differs for boys and girls.

SEASONAL VARIATION IN PHYSICAL ACTIVITY

The socioecological perspective to health behaviours has been widely advocated (149). This approach suggests that, in addition to personal, social, and institutional influences, environmental factors – including seasonal characteristics – may have an impact on behaviour (149). Seasonal variation in children's PA has been reported in many countries, including in Europe, the USA, and Australia (133, 141, 150-152). Activity levels are generally lowest in the winter, when dark evenings and cool, wet weather is thought to reduce PA participation (133, 150-152). Dias et al. found that a greater percentage of children met the TPA and MVPA guidelines when the hours of daylight were more than 12 hours (133). Moreover, the relationships between seasonal characteristics and PA has been shown to vary between countries (150), probably due to cultural adaptations to the markers of seasons (e.g., climate, weather and day length). For example, there may be settings in which the physical environment supports outdoor active play in wet weather or the cultural environment promotes PA even in cold weather (e.g., in areas with snow).

Few studies have examined seasonal variation in PA among preschool-aged children, and the results of these are inconclusive (140, 150). However, it has been suggested that the influence of weather conditions may be stronger for preschool-aged children than for older children and adolescents (150). Understanding how seasons influence PA is a useful step in developing interventions to maintain activity levels throughout the year. Seasonality is also relevant in the context of assessing population prevalence or secular trends in PA behaviour because estimates may be biased if data are collected within a restricted period of the year (153). The existing evidence on seasonal variation in PA is, however, mainly drawn from between-subject comparisons of cross-sectional data (153), which may be subject to bias. Moreover, most longitudinal studies have been restricted to small samples (153), which offer little scope for the examination of modifiers such as sex and age.

1.7 THE PRESCHOOLS' ROLE FOR PHYSICAL ACTIVITY

Although parents are the primary care providers of young children, children under the age of six also spend large amounts of time in Early Childhood Education and Care (ECEC) services in many countries. As social and physical environments have a strong influence on child behaviour and development (154), ECEC services have a critical role in providing opportunities for children to be physically active (67). The nature and scale of ECEC services have changed dramatically in most developed countries in the last two decades (155). In western Europe there has been an increase in children attending preschools, kindergartens, and other types of ECEC's (hereafter referred to as 'preschools') rising from 20% to 90% over the period of 1994 to 2014 (155). In Norway in particular, 97% of all 3-5 year-old children are enrolled in preschool (25) for an average of 33 hours per week (26). With both enrolment rates and time spent in the preschool setting being high, the potential to influence children's PA behaviour is significant. Importantly, the wide reach makes the preschool setting especially relevant with regards to favourably influencing less active children who come from less active families. Thus, the preschool has the opportunity to provide social and physical environments that support PA for all children – including those most in need (4).

Knowledge of where and when preschoolers are physically active is essential to initiate interventions aimed to increase PA in young children and to make specific recommendations for attaining the guideline amounts. Several studies have investigated children's PA levels during preschool hours (21), with results being highly variable and MVPA levels ranging from 1.3 to 22.7 minutes per hour (21). Moreover, some studies have investigated how PA differ over the course of a day and a week (133, 156-162). However, most of these studies are limited by small sample sizes (size range, N=188-341) (156, 158, 160, 162), and, more importantly, results are conflicting regarding where and when children are most active. Dias et al. found that levels of TPA and MVPA were greater on weekdays than on weekends (133). Furthermore, some studies have reported that children are less active during preschool hours (157, 162), while others have found that children are more active during preschool hours than in their time out-of-care (156, 160, 161). Also, there is limited evidence as to whether the observed sex and age differences in PA are equally present when children are in preschool vs. out-of-care. Thus, more research is needed to determine setting-specific PA and, by extension, the preschools' role for children's PA.

1.8 PHYSICAL ACTIVITY AND FUNDAMENTAL MOTOR SKILLS

MOTOR SKILL DEVELOPMENT AND PHYSICAL ACTIVITY

Motor skill proficiency was traditionally thought to naturally progress as children age. Today, most researchers agree that FMS are not pre-wired abilities, but rather a result of adaptation to stimuli and learning experiences promoted through complex interactions of biological, psychological, instructional, and environmental constraints (29, 109, 163). This means, for example, that a child's FMS is affected by both the physical- and sociocultural environment, and that motor development happens through opportunities to learn and practise new skills, and through receiving feedback and encouragement on motor behaviour (78). As such, children develop their FMS through engagement in PA (30); and from an early age, an adequate level of FMS is necessary to move and control the body to enable participation in physically active play (108).

Proficiency in FMS is further considered essential to maintain sufficient levels of PA over the longer term (164, 165). In 2008, Stodden and colleagues stated that previous research had *'[…]failed to consider the dynamic and synergistic role that motor competence plays in the initiation, maintenance, or decline of physical activity'* (166). They introduced a new conceptual model (166) that addressed the potential role of the development of FMS in promoting either positive or negative trajectories of PA. Stodden et al. hypothesised a bi-directional relationship between FMS and PA, a relationship strengthened by age and which changes at different stages of a child's development (166, 167). While Stodden et al. hypothesised that engagement in PA was essential for the development of FMS during the early years, they suggested FMS levels might become of greater importance for PA participation with increased age, as the child become more motor competent (166). The model further addresses the role of FMS and PA in relation to weight status, with fitness and perceived FMS level being mediating variables between PA and FMS (see **Figure 1**).

The synergistic nature of the relationships among the variables in the Stodden et al. model is said to promote either positive or negative trajectories of PA, FMS, fitness, and weight status across childhood and adolescence. For example, individuals with low FMS may exhibit insufficient levels of PA and fitness and be at greater risk of obesity. Moreover, the model provides a testable framework of multiple individual, behavioural, and psychological constraints that might interact to produce favourable or unfavourable child health and developmental outcomes.

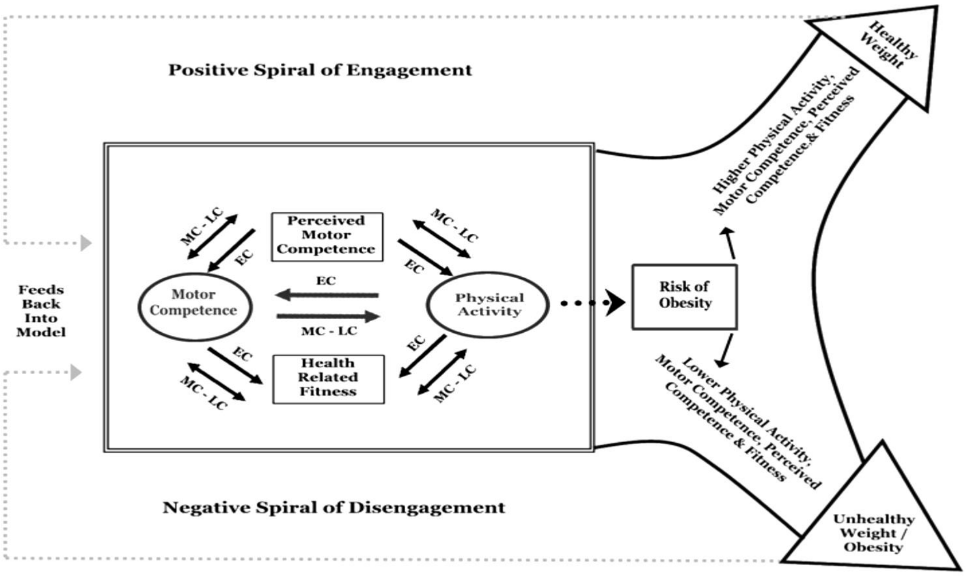

Figure 1.*Developmental model proposed by Stodden et al. (166) hypothesizing developmental relationships between fundamental motor skills/motor competence, health-related fitness, perceived motor competence, physical activity, and weight status/risk of obesity through childhood. EC: Early childhood; MC: Middle childhood; LC: late childhood/adolescence. Reprinted from Stodden et al. (166) with permission from Taylor & Francis (http://www.tandfonline.com).*

INTENSITY SPESIFIC RELATIONSHIPS

A positive cross-sectional relationship between FMS and PA in childhood is well documented (165, 168), although few large-scale studies using objective measures of PA have examined this relationship in preschool-aged children. Furthermore, studies of preschool populations have shown weak-to-moderate, positive relationships, but the specific pattern and strength of the associations tends to differ by sex, PA intensity, motor skill domain, and time of week (29, 30).

A systematic literature review by Figueroa and An (2017) supports a stronger, positive association between MVPA and FMS, compared to LPA, in preschoolers (30). Moreover, evidence is conflicting regarding the role of LPA for FMS, as some studies have found a positive association (169, 170) and others have not (171, 172). Most studies investigating relationships between objectively measured PA and FMS in preschoolers have focused primarily on associations with MVPA. This narrow perspective leads to a substantial loss of information from accelerometry, as it ignores the possible influence of LPA, MPA, and VPA and thus increases susceptibility to residual confounding for the analysed variables (173). Few studies have investigated the association between SED and FMS, though some have demonstrated that lower SED is associated with better FMS (171, 174, 175). However, these studies have not controlled for MVPA and are, thus, likely to be affected by residual confounding.

In addition, the interpretation and comparison of findings on PA intensity-specific influences across studies are hampered by the great variability in accelerometer cut points used (9, 72), which leads to the capturing of somewhat different PA intensities. In turn, this leads to uncertainty regarding which PA intensities are most strongly related to FMS. This challenge can be solved by analysing the intensity spectrum as a whole, irrespective of pre-defined cut points and selected PA intensity ranges (62). Because the different PA intensity variables derived from accelerometry are strongly correlated, common statistical methods (i.e., multiple linear regression) are unsuited to exploring the association pattern across the PA spectrum with a given outcome. Therefore, we need novel statistical methods to overcome this challenge (62, 176).

LONGITUDINAL RELATIONSHIPS

Although most cross-sectional studies support a positive association between FMS and PA in childhood (29, 164), few longitudinal studies using objective measures of PA exist, and thus, the direction of these associations remains unclear. A recent study by Schmutz et al. showed that FMS predicted higher accelerometer derived TPA and MVPA over a period of 12 months in children aged 2-6 years at baseline (N=555) (147). In addition, Venetsanou and Kambas (177) explored the longitudinal associations between FMS in preschoolers and PA measured with pedometers 10 years later (N=106), and found that FMS during the preschool years predicted higher PA levels in adolescence. However, this study did not consider intensity-specific PA (177). Importantly, though, these studies did not adjust for baseline PA levels, limiting their conclusions with regard to the direction of the association. Lopes et al., on the other hand, performed a longitudinal analysis showing that FMS positively predicted change in MPA, MVPA, and TPA in adolescents (N=103) at two-year follow-up (178). Similarly, Larsen et al. found that FMS positively predicted change in MVPA at three-year follow-up in their sample of 6-12 year-old Danish children (N=673) (179).

Since previous longitudinal studies primarily have focused on FMS as a determinant of PA, less is known about the predictive role of PA for FMS development. Although Barnett et al. found that MVPA at age 3.5 years was positively associated with locomotor skills at age five in a sample of preschoolers (N=127) (180), their results are limited by the lack of adjustment for baseline levels of the outcome. To our knowledge, only one previous study has investigated the bi-directional, prospective relationship between objectively measured PA and FMS in childhood. Lima et al. found that VPA and FMS presented a direct positive, bi-directional, prospective association over a seven-year follow-up period of 513 children aged 6-13 years in the Copenhagen School Child Intervention Study (181). Thus, their results correspond with the proposed model of Stodden et al. (166). The authors urge future studies to investigate whether the strength of the associations between PA and FMS change during childhood (181). In addition, Lima et al. only tested FMS within the locomotor/dynamic balance domain; thus, more longitudinal research including other aspects of FMS (e.g., object control skills) is needed. Moreover, it is yet to be investigated whether these relationships differ among boys and girls, and between the youngest vs. oldest children within the preschool age-range. As highlighted by Cliff et al. in 2009, longitudinal studies are warranted to investigate interactions of sex and age on the prospective relationships between domain-specific FMS and intensity-specific PA to better understand the causal nature of the relationship between PA and FMS (182).

Increased knowledge of the longitudinal associations between PA and FMS will provide a stronger rationale for the development of FMS and the promotion of PA within the preschool population. Considering the benefits of both PA and FMS for future health, an improved understanding of these variables' interrelationships is a relevant public health focus.

2. RESEARCH GAPS AND STUDY AIMS

2.1 RESEARCH GAPS

To understand prevalence rates across areas with different cultural, social, and physical environments, as well as areas with different seasonal characteristics, large studies are needed from a wide range of countries. Currently, no large-scale study has determined PA objectively in Norwegian preschoolers. Evidence is conflicting regarding how PA develops by age in preschoolers and whether sex differences in PA are evident across age. Furthermore, it has been observed that children's activity levels exhibit a seasonal pattern, but this pattern seem to differ between environments and settings (150). ICAD-data suggest that the impact of season on PA levels is stronger in preschool aged children than in older children (150). However, few investigations target seasonal variations in preschoolers; thus, further research is warranted (150).

Objective monitoring of PA in preschoolers has increased greatly in recent years. However, most studies have only reported PA during preschool hours or total PA regardless of setting, and they have not considered the potential individual differential effect of time and place on children's PA. The few studies that have investigated this, are limited by small sample sizes (156, 158, 160, 162) and, more importantly, results are conflicting regarding where and when children are most physically active.

Only a small number of studies have examined the cross-sectional relationship between PA and FMS in preschool-aged children; and although most studies show weak-to-moderate, positive relationships, findings are inconsistent – especially with regards to which PA intensities that are most strongly related to FMS (29, 30). Moreover, the physical activities and intensities captured by accelerometry differ between studies, leading to confusion about these associations.

The model proposed by Stodden and colleagues, with regards to the direction of the relationship between PA and FMS, has had limited testing in young children. Therefore, it is uncertain which factor is the driving force during early childhood, i.e., PA for FMS development, or vice versa – FMS for PA development. To the best of our knowledge, no previous study has investigated the prospective, bi-directional relationship between PA and FMS in preschoolers using objective measures of PA.

2.2 STUDY AIMS

The overall aims of this thesis was to increase knowledge about PA levels among Norwegian preschoolers, and to investigate cross-sectional and longitudinal associations between PA and sex, age, season, setting and FMS. The specific aims of the four studies constituting this thesis were as follows:

I. To determine levels of PA by sex and age in a large cross-sectional sample of preschoolers (1) and to investigate seasonal variation in PA by sex and age in a subsample of children using longitudinal data across seasons (2).

II. To describe the distribution of PA and SED, during preschool hours vs. time out-of-care, and on weekdays vs. weekends (1), and to investigate differences in PA patterns across sex, age, and overall MVPA levels (2).

III. To determine the intensity pattern associated with FMS in preschool-aged children, using the whole PA intensity spectrum.

IV. To examine the prospective, bi-directional relationship between intensity-specific PA and domain-specific FMS in preschool-aged children over a period of two years.

3. MATERIAL AND METHODS

3.1 STUDY SAMPLE, STUDY DESIGNS, AND DATA COLLECTION

The present thesis is based on the *'Sogn og Fjordane Preschool Physical Activity Study'* (PRESPAS), which is both a large cross-sectional study and a longitudinal study with a two-year follow-up time. PRESPAS was conducted in the county of Sogn og Fjordane in western Norway (**Figure 2**) between September 2015 and October 2017. Sogn og Fjordane county (land area: 17 709 km^2; population number: 110 230 (183)) is mainly a rural area with scattered population and nature defined by fjords, mountains, and coast line (west). Recruitment of participants was performed in three steps: at the municipality level, at the preschool level, and at the child (parent) level.

First, we invited 15 out of 26 municipalities in the county to participate in the study. Municipalities were strategically selected based on the population average education level, population size, geographical location, average number of children per preschool, and average number of children per preschool teacher. One municipality choose not to take part in the study.

Second, we recruited preschools through the municipality preschool boards. All 74 preschools within the 14 participating municipalities that had at least six children in the appropriate age group (i.e., born in 2010, 2011 and/or 2012) were invited. The criterion for the minimum number of children was set for practical reasons and caused the exclusion of 10 preschools. Among the 74 preschools invited, three did not want to participate, and three were excluded because they did not manage to recruit children to the study. Thus, 68 preschools (92% of those invited) participated in the study.

Third, we invited all children born in 2010-2012 within the 68 participating preschools to take part in the study. In total, 1925 children were invited, constituting 49% of the total population of preschoolers (i.e., children born in 2010-2012 attending preschool at the time of recruitment) in Sogn og Fjordane County in 2015 (26). In total, 1308 of the 1925 invited children participated in the study (68% of those invited; 34% of the total population of preschoolers in Sogn og Fjordane county).

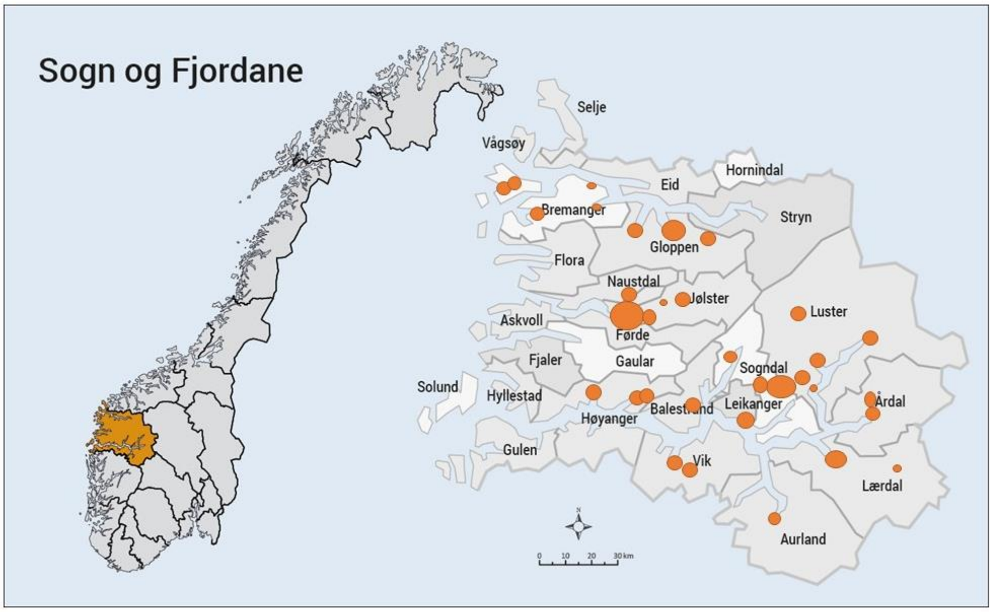

Figure 2. *Map of Norway and 'Sogn og Fjordane' county, with municipalities and the location of the 68 preschools included in PRESPAS. Larger dots indicates several preschools within the same area. The University Campus is located in 'Sogndal'.*

For the cross-sectional sample, PA, FMS, anthropometry, and questionnaire data was collected at one time point throughout the baseline year (2015-2016). Additionally, we invited all children from 20 of the preschools (n=376) *already included in the cross-sectional sample* to perform three repeated measurements of PA and anthropometry across the baseline year (autumn of 2015 (September-December), winter of 2016 (January-March), and spring/summer of 2016 (April-June)), and one follow-up measure two years later (September-October of 2017) (**Figure 3**). All children invited to the longitudinal part of the study participated at minimum one time point during the baseline year.

The follow-up measurement consisted of one PA registration period, one measurement of anthropometry, and one evaluation of FMS. Thus, the longitudinal sample provided both longitudinal data collected within a timeframe of 10 months (baseline) (PA and anthropometry), and over a two-year period (PA, FMS, and anthropometry). One of the three baseline measurements of PA from the longitudinal sample were included in the cross-sectional material (autumn 2015 for 12 preschools and winter 2016 for 8 preschools), as determined a priori to achieve a balance between seasons for the cross-sectional analyses.

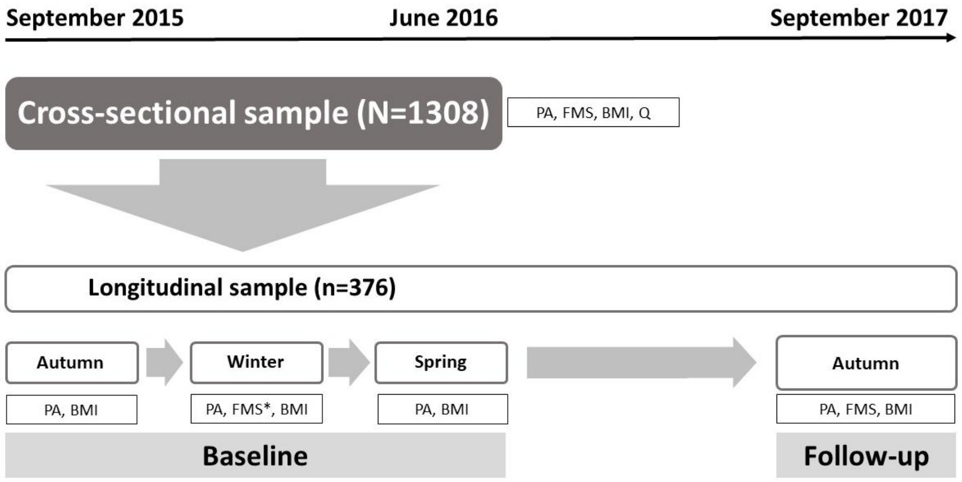

Figure 3. *Illustration of study samples and time of measurements. PA: Physical activity; FMS: Fundamental motor skills; BMI: Body mass index; Q: Questionnaire. *FMS: all children were tested at one time point during the baseline year, however, 2/3 of the children were tested during January-February 2016, and 1/3 were tested in October 2015.*

3.2 SAMPLE SIZE CALCULATIONS

The sample size calculation was performed on the basis of finding statistically significant interactions between sex, weight status, PA/SED, and FMS vs. patterns of PA/SED during preschool hours vs. time out of care, and at the same time ensure a large sample of preschools to provide a basis for examining variation at the preschool level. Depending on the estimated effect size (ES 0.4) and cluster effect (intra class correlation: ICC 0.20), the required number of participants was calculated to ~ 1150 children distributed in ~ 65 preschools, given $\alpha = 0.05$, $1\text{-}\beta = 0.80$, r for repeated measurements = 0.5 and n per cluster ~ 17 after estimated drop-out (not participation + missing valid measurements for PA) of 30% per preschool (mean of 25 children / preschool in Sogn og Fjordane). Based on previous studies (22, 156, 184, 185), the ICC was expected to be relatively high (mean ~ 20%). Based on this conservative sample size calculation, we aimed to recruit a minimum of 65 preschools and 1150 children to PRESPAS. Due to the expected attrition among children (30%), we aimed to invite ≈1900 children to participate in the study.

3.3 ETHICS

Parents of all participating children received oral and written information about the study and provided written consent prior to testing. Preschools (at baseline and follow-up) and schools (at follow-up) received information about the study and consented to participate before testing took place. Children were provided with an explanation of the measurements according to their level of understanding and all testing took place in safe and familiar environments. All procedures' and methods included in the PRESPAS conformed to the ethical guidelines defined by the World Medical Association's Declaration of Helsinki and its subsequent revisions (186). The Norwegian Centre for Research Data (NSD) approved the study (reference numbers: 39061 (cross-sectional study) and 48016 (longitudinal study)) (**Appendix I and II**).

3.4 PROCEDURES

PHYSICAL ACTIVITY

PA was measured using the ActiGraph GT3X+ accelerometer (ActiGraph, LLC, Pensacola, Florida, USA) (84). Children wore an elastic belt with the accelerometer on the right hip, and were instructed to wear the monitor at all times for 14 consecutive days, except during water-based activities and while sleeping (at night). Accelerometers were initialized with a sampling rate of 30 Hz and analysed using 10-second epochs **(Study I and II)** and 1-second epochs **(Study III and IV)** using the KineSoft software (KineSoft version 3.3.80, Loughborough, UK). Periods of ≥20 min of zero counts were defined as non-wear time (187). Our criterion for a valid day was ≥480 min of wear time accumulated between 06:00 and 24:00 hours. We included all children who provided ≥4 days (3 weekdays and 1 weekend day) of valid PA data in the analyses.

Time defined as 'preschool hours' were based on average delivery/pick-up time for the current sample (time-stamped data), defined as between 08:30 am and 15:29 pm on weekdays (SD ± 0:30 hours for both time points). All leisure time, including 'morning' (06:00–08:29 hours) and 'afternoon' (15:30–23:59 hours) on weekdays, was defined as 'time out-of-care'. Participants included in the analysis of PA during preschool hours and time out of care (**Study II**) had to have ≥30 min wear time in the 'morning', ≥270 min wear time during 'preschool hours', and ≥180 min in the 'afternoon' on weekdays. For the cross-sectional sample (**Study I-III**), children performed one 14-day registration of PA. For the longitudinal sample (**Study I and IV**) children were asked to perform three PA-registration periods during the baseline year (autumn 2015, winter, and spring/summer 2016) (**Study I and IV**), and one PA-measurement at follow-up (autumn 2017) (**Study IV**), providing up to six weeks of PA data at baseline, and two weeks at follow-up. An average of the three PA measurements is used as baseline in **Study IV** (in case of one missing observation, a mean of the two remaining PA registrations were used).

PA outcomes were TPA (cpm) and intensity-specific PA, reported as SED (<100 cpm), LPA (101-2295 cpm), MPA (2296-4011), VPA (≥4012 cpm), and MVPA (min/day) (≥2296 cpm), as proposed by Evenson et al. (97) for **Study I-IV** (vertical axis only). Additionally, we reported the proportion of children who achieved the guideline amount of > a mean of 60 min/day of MVPA (**Study I and IV**). Because of the ongoing discussion regarding which cut points to be used in preschool populations (86), we have provided supplemental results derived from the Pate et. al. cut points (MVPA > 1680 cpm, SED < 148 cpm) (93) (**Study I**). We further created 33 PA variables of total time (min/day) to capture movement in narrow intensity intervals throughout the spectrum from all axes (vertical, antero-posterior, and medio-lateral) (**Study III**); 0–99, 100–249, 250–499, 500–999, 1000–1499, 1500–1999, 2000–2499, 2500– 2999, 3000–3499, 3500–3999, 4000–4499, 4500–4999, 5000–5499, 5500-5999, 6000–6499, 6500-6999, 7000–7499, 7500–7999, 8000–8499, 8500–8999, 9000–9499, 9500–9999, 10000–10499, 10500–10999, 11000–11499, 11500–11999, 12000–12499, 12500–12999, 13000–13499, 13500–13999, 14000–14499, 14500–14999, and ≥ 15000 cpm.

MOTOR SKILL ASSESSMENT

To measure FMS, we developed a test battery guided by the TGMD-3 (113). We modified this test battery to reduce the participant and researcher burden, and at the same time cover the three main domains of FMS by including balance skills (44, 120). We, therefore, included six movement tasks from the TGMD-3 battery (run, horizontal jump, hop, catch, overhand throw, and kick), in addition to three movement tasks within the balance domain (single leg standing, walking line forward, and walking line backward) from the Preschooler Gross Motor Quality Scale (PGMQ) proposed by Sun et al. (120), in our assessment of FMS. The specific skills were selected based on their relevance (e.g., some of the movement tasks in the TGMD-3, like the baseball strike and dribble, are less common and therefore less relevant in assessments of Norwegian children), and variety (e.g., including object control skills related to both hands and feet, and adding both static and dynamic balance tests) in terms of broadly capturing children's skills within the three FMS domains.

FMS were measured one time at baseline (autumn 2015 - winter 2016) in all children participating in the cross-sectional and longitudinal part of the study (**Study III and IV**), and one time at follow-up (autumn 2017) (**Study IV**). Children were evaluated in small groups (4–5 children) during preschool/school hours and were asked to perform the nine movement tasks in a safe environment with enough space to move freely. Each child performed each skill twice and skills were completed in a standardised order, taking approximately 25–30 minutes per group. The test teams consisted of one instructor who provided a verbal description and demonstration of the required skill, while a separate rater observed and scored the performance.

We administered the FMS measurements according to TGMD-3 (locomotor and object control skills) and PGMQ (balance skills) protocols; using both the original sum scores (**Study IV**) and mean scores (**Study III**). In both cases, children were scored quantitatively based on a qualitative evaluation of whether the child did or did not demonstrate specific process criteria for each skill item based on the original scoring procedures for TGMD-3 and PGMQ (marked as either absent: '0' or present: '1') (113, 120). The children had two trials per task/item, and the score from trial 1 and 2 were summed, thus - providing a score of 0 to 2 points per criteria. The criteria scores were then summed or averaged for each item and each domain. The maximum sum domain scores were 24 points for locomotor and balance skills (4 criteria per item, 3 items), and 20 points for object control skills (3 criteria for 'catch' and 'kick', 4 criteria for 'overhand throw') (**Study IV**). In contrast to the original scoring protocols (sum scores) (113, 120), the use of mean scores ensures similar weight to all skills within the domains, independent of the number of assessed criteria, all with a range from 0 to 2 points (**Study III**).

In total, six raters took part in the assessment of FMS. Prior to the data collection, all assessors were thoroughly trained in how to instruct and score children in the different movement tasks. Inter-rater reliability (ICC), based on in-field concurrent scoring of 26 children, was 0.90 for the locomotor items, 0.74 for the object control items, and 0.86 for the balance items.

ANTHROPOMETRY

We assessed children's body weight and height during preschool hours. Body weight was measured to the nearest 0.1 kg using an electronic scale (Seca 899, SECA GmbH, Hamburg, Germany), and height was measured to the nearest 0.1 cm with a portable stadiometer (Seca 217, SECA GmbH, Hamburg, Germany). Body weight and height were measured at the same time as PA during baseline and follow-up (i.e., one time for the cross-sectional sample (**Study I-III**), three times during the baseline year for the longitudinal sample (**Study I and IV**), and one time at follow-up (**Study IV**). Body mass index (BMI, kg/m^2) was calculated and used as a continuous variable in the association analyses. Children were additionally classified as normal weight, overweight, or obese based on criteria proposed by Cole et al. (188) for descriptive purposes.

CO-VARIATES

Children's sex, birth date, and parental socioeconomic status (SES, based on the highest education level and the highest yearly income of mother or father) were assessed using a questionnaire completed by the child's mother and/or father at baseline (**Appendix VI**). Age on test date was calculated.

3.5 STATISTICAL ANALYSES

Across the four studies, children's characteristics, FMS, PA, and SED were reported as frequencies, means, and standard deviations (SD), except for the number of valid days of accelerometer data, which was reported as the median. Age groups were based on median split (50% youngest, 50% oldest) and age-categories ($\leq$ 3.49 years = 3; 3.50–4.49 years = 4; 4.50–5.49 years =5; $\geq$5.50 years = 6) for descriptive purposes (**Study I and IV**).

We tested for differences in characteristics between included and excluded children, by age, and between boys and girls, using a two-level linear mixed model including random intercepts for preschools for continuous outcomes, and a generalized estimating equation defining preschools as the cluster variable using an exchangeable correlation structure for categorical outcomes. Analysis was adjusted for the following co-variates unless stated otherwise: age, sex, parental income and education level, BMI, accelerometer wear time and season (when investigating associations with PA), FMS score person (when investigating associations with FMS).

Multivariate pattern analyses were performed using the commercial software Sirius version 11.0 (Pattern Recognition Systems AS, Bergen, Norway) (**Study III**). All other analyses were performed using IBM SPSS version 24 (IBM SPSS Statistics for Windows, Armonk, NY; IBM Corp., USA). $p<0.05$ indicated statistically significant findings.

STUDY I

In the cross-sectional analyses, we used a two-level model, including random intercepts for preschools, to analyse absolute values. In analyses of repeated measurements, we added random intercepts for children to take the repeated measurements into account (i.e., a three-level model). The longitudinal data were analysed using absolute values at each time point as the primary analysis. However, we also performed a sensitivity analysis using change scores between autumn (baseline) and winter, and between winter and spring/summer. PA was the outcome in all models.

Main effects of age, sex, and season were determined by including these variables as independent variables while controlling for the co-variates listed above. We thereafter tested several possible moderators of PA by including the interaction terms sex*age, sex*season, and age*season in the models specified above. Finally, the three-way interaction sex*age*season was included, thus allowing for the evaluation of a full factorial model. All models using absolute values were run in both the cross-sectional and the longitudinal sample.

STUDY II

To account for the clustering of observations within preschools and the repeated measurement across settings, all analyses for continuous outcomes were performed using a three-level linear mixed model that included random intercepts for children and preschools (i.e., observations were clustered within children and children were clustered within preschools).

We performed two types of main analyses. First, we compared the amount of PA during preschool hours vs. time out-of-care and on weekdays vs. weekends. Second, we analysed sex, age, and overall MVPA as moderators of PA across settings/time of week by analysing interactions for setting/time of week according to these characteristics (i.e., sex*setting, age*setting, overall MVPA*setting, etc.), and we reported the associated p-values. Main effect estimates (β coefficients) and 95% confidence intervals (CI) were calculated separately for preschool hours, time out-of-care, weekdays, and weekend days. Interaction analysis was performed in two steps across both comparisons (preschool hours vs. time out-of-care, weekdays vs. weekends). First, we tested the interactions of sex*setting / age*setting (in the same model) and sex*time of week / age*time of week (in the same model), and second, we included the interaction of overall MVPA*setting / MVPA*time of week to the above-mentioned models. ICC was calculated as the variance in PA explained by preschool divided by total variance.

STUDY III

Interrelationships between all 33 PA variables, and between total and domain-specific FMS scores, were tested using unadjusted, bivariate correlation analyses. Prior to the multivariate pattern analysis, we performed linear mixed model regression analyses with all FMS variables as dependent variables in separate models, including age, sex, BMI, season, accelerometer wear time, and FMS score person as independent variables, to obtain residuals from these models to adjust the outcomes for these variables and remove confounding. Associations between PA and FMS were thereafter determined using Pearson's *r* and multivariate pattern analysis (Partial least squares (PLS) regression analysis), as shown previously (62).

PLS regression analysis (189) determined the multivariate PA signature of the FMS variables (outcome variables), including all PA variables as explanatory variables. PLS regression decomposes the explanatory variables into orthogonal linear combinations, while simultaneously maximizing the covariance with the outcome variable. Thus, in contrast to ordinary least squares regression, PLS regression can handle completely collinear variables.

Monte Carlo resampling (190) with 100 repetitions was used to optimize the predictive performance of the models by randomly keeping 50% of the subjects as an external validation set when estimating the models. For each validated PLS regression model, a single predictive component was subsequently calculated by means of target projection (191, 192). By this transformation, all the predictive variance in the intensity spectrum related to FMS is expressed in a single intensity vector. Selectivity ratios (SRs) was determined as the ratio of this explained predictive variance to the total variance for each PA intensity variable (193, 194). The results are displayed in an SR plot indicating positive or negative associations with FMS, in addition to the models' explained variances (R^2). Confidence intervals were constructed around each SR and used to assess the significance of the SR for each PA variable.

We analysed the sample as a whole, and further performed sensitivity analyses according to sex and age (median split), pattern associations are reported as Pearson's r.

STUDY IV

We used Pearson's correlations, change scores, and paired sample t-test to describe the differences in anthropometrics, FMS, and PA and SED between baseline and follow-up. The prospective association analyses were performed using a two-level linear mixed model including random intercepts for children. The outcome at follow-up was the dependent variable, and the predictor, the baseline level of the outcome and the following co-variates were included as independent variables: sex, baseline age, baseline BMI, parental education and income level, accelerometer wear time at both time points (when PA was the outcome) and assessor of FMS at both time points (when FMS was the outcome). The analyses was repeated using both PA (LPA, MPA, VPA, MVPA, TPA), SED, and FMS (locomotor, object control, and balance skills) as predictors and outcomes. For reporting of prospective associations, FMS and PA variables were standardized to z-scores for ease of interpretation, thus, the regression coefficients are given in SD units.

Since most children (two-thirds) changed cluster (from preschool to school) between baseline and follow-up, accounting for clustering of observations among preschool/school made less sense than in the other analyses. However, we performed sensitivity analysis including random intercepts for clusters of preschool or school at follow-up (i.e., a three-level model), but because the three-level model did not change any conclusions, we chose to present the results from the two-level models. Furthermore, we tested for interactions by sex (baseline exposure (PA or FMS) x sex) and age (baseline exposure (PA or FMS) x baseline age). In all models, FMS, SED and PA variables were analysed one by one to avoid multi-collinearity.

4. SUMMARY OF RESULTS

4.1 STUDY I

Aims: To determine levels of PA by sex and age in a large cross-sectional sample of preschoolers (1) and to investigate seasonal variation in PA by sex and age in a subsample of children using longitudinal data across seasons (2).

Description of the samples

Of the 1308 children that participated in PRESPAS, 1154 (88%) provided valid accelerometer data and were included in the analysis for **Study I** (**Table 1**). Children had a median of 13 valid days of PA registration (≤ 7 days: 4.4%; 8–11 days: 44.0%; ≥ 12 days: 51.6%), and on average, 698 (43) wear minutes per day. The majority of children had a normal weight status (82%), were born in Norway (97 %), and had parents born in Norway (mothers: 89%; fathers 88%). Attrition analyses showed that the 1154 included children were slightly older than the excluded children (p=0.012) and had parents with higher income- (p=0.049) and education (p=0.003) levels. The included and excluded children did not differ regarding BMI (p=0.486) or sex (p=0.954). Participants' characteristics from the longitudinal sample did not differ from those of the cross-sectional sample (**Table S2 in Study I**).

Physical activity levels

Overall, children had a mean TPA (SD) of 754 (201) cpm and 66 (21) min of MVPA per day (**Table 1**). Boys and girls spent 10.2 (2.9)% and 8.6 (2.6)% of their daily time in MVPA, respectively. Further, boys and girls spent 48.1 (6.7)% and 50.2 (6.9)% of their daily time in SED, respectively, whereas they were in LPA for 41.4 (5.3)% and 40.7 (6.0)% of their time, respectively. In total, 55% of the children accumulated a mean of ≥60 min of MVPA per day using the Evenson et al. MVPA cut point (97). To compare, 95% achieved this guideline amount using the Pate et al MVPA cut point (93) (**Table S1 in Study I**). Boys and older children had a higher level of compliance with the recommendation than girls and younger children did (**Table 2**).

Table 1. *Children's characteristics*

	Total sample N = 1154	**Boys n = 596 (52%)**	**Girls n = 558 (48%)**
Age (years)	4.7 (0.9)	4.8 (0.9)	4.7 (0.9)
Ethnicity of child (n (%))			
Born in Norway	1017 (97%)	527 (97%)	490 (97%)
Mother born in Norway	927 (89%)	482 (89%)	445 (88%)
Father born in Norway	919 (88%)	483 (89%)	436 (86%)
Body mass (kg) (n = 1024)	19.4 (3.3)	19.6 (3.2)	19.2 (3.3)
Height (cm) (n = 1024)	109.1 (7.5)	109.8 (7.5)	108.3 (7.3)
BMI (kg/m2) (n = 1024)	16.2 (1.4)	16.2 (1.3)	16.3 (1.5)
Age-specific weight status (n (%))			
Normal	920 (82%)	490 (85%)	430 (79 %)
Overweight	178 (16%)	79 (14%)	99 (18 %)
Obese	28 (3%)	9 (2%)	19 (4 %)
Parental education level*			
Upper secondary school	111 (10%)	57 (10%)	54 (10%)
University < 4 years	458 (42%)	233 (42%)	225 (43%)
University ≥ 4 years	521 (48%)	270 (48%)	251 (47%)
Parental income level*			
< 32500 EUR	59 (6%)	30 (6%)	29 (6%)
32500-62000 EUR	644 (62%)	345 (64%)	299 (60%)
> 62000 EUR	337 (32%)	166 (31%)	171 (34%)
Season of measurement (n (%))			
Winter	566 (49%)	283 (48%)	283 (51%)
Spring/Summer	222 (19%)	124 (21%)	98 (18%)
Autumn	366 (32%)	189 (32%)	177 (32%)

All values are mean ± SD unless stated otherwise; SD: Standard deviation; weight status defined according to Cole et al., 2000; winter: December-March; spring/summer: April-June; autumn: September-November.
*Parental education level and yearly income: highest level of mother or father used.

Table 2. *Children's wear time, sedentary time and PA levels (mean ± SD) and compliance with MVPA recommendations (%)*

	Total	**3-yr-olds**	**4-yr-olds**	**5-yr-olds**	**6-yr-olds**
Total sample	*N = 1154*	*n = 112*	*n = 338*	*n = 439*	*n = 265*
Wear time (min/day)	700 (42)	683 (48)	688 (39)	704 (40)	715 (39)
Total PA (cpm)	754 (201)	646 (140)	730 (210)	758 (182)	822 (215)
SED (min/day)	343 (54)	337 (59)	339 (52)	344 (53)	350 (54)
LPA (min/day)	288 (41)	291 (40)	286 (42)	289 (40)	286 (41)
MPA (min/day)	45 (14)	38 (11)	41 (12)	47 (13)	51 (14)
VPA (min/day)	20 (10)	13 (6)	18 (10)	20 (10)	25 (12)
MVPA (min/day)	66 (21)	52 (15)	60 (19)	68 (19)	76 (22)
≥ 60 min MVPA/day (%)	55	25	44	62	72
Boys	*n = 596*	*n = 57*	*n = 167*	*n = 227*	*n = 145*
Wear time (min/day)	704 (42)	692 (42)	692 (38)	707 (45)	715 (37)
Total PA (cpm)	790 (202)	651 (145)	774 (209)	791 (192)	858 (200)
SED (min/day)	337 (52)	338 (61)	330 (49)	340 (53)	341(52)
LPA (min/day)	291 (39)	296 (41)	292 (41)	292 (37)	289 (37)
MPA (min/day)	50 (14)	42 (12)	46 (13)	51 (13)	55 (15)
VPA (min/day)	21 (11)	13 (6)	20 (10)	22 (10)	26 (11)
MVPA (min/day)	72 (21)	55 (16)	66 (20)	73 (19)	82 (21)
≥ 60 min MVPA/day (%)	66	30	56	73	79
Girls	*n = 558*	*n = 55*	*n = 171*	*n = 212*	*n = 120*
Wear time (min/day)	696 (42)	674 (53)	685 (40)	701 (34)	714 (42)
Total PA (cpm)	714 (192)	641 (136)	686 (203)	720 (164)	777 (225)
SED (min/day)	350 (54)	336 (57)	347 (53)	350 (53)	361 (54)
LPA (min/day)	283 (43)	286 (38)	280 (44)	286 (42)	281 (46)
MPA (min/day)	41 (11)	35 (8)	37 (10)	43 (12)	45 (12)
VPA (min/day)	18 (10)	14 (7)	16 (10)	19 (9)	23 (12)
MVPA (min/day)	59 (18)	48(13)	54 (17)	62 (17)	68 (20)
≥ 60 min MVPA/day (%)	43	18	29	50	61

SD: Standard deviation; SED: Sedentary time; LPA: Light physical activity; MPA: Moderate physical activity; VPA: Vigorous physical activity; MVPA: Moderate-to-vigorous physical activity.

Associations (main effects) between physical activity and sex, age, and season

Table 3 gives an overview of the results on main effect associations and interactions between PA and SED and the following factors: sex, age, and season in the longitudinal sample (for cross-sectional sample, see **Table S3 in Study I**). Sex differences in TPA, MPA, VPA, MVPA and SED were similar in both samples, with boys accumulating more PA (all intensities) and less SED than girls ($p<0.01$). Further, the same trend was found in both samples regarding associations between PA and age, with an increase in TPA, MPA, VPA and MVPA by age, and a decrease in LPA by age (all $p<0.01$), while the amount of SED was similar across ages.

In analyses of associations between PA and season, the results were somewhat conflicting between the cross-sectional and the longitudinal sample. In the cross-sectional sample, children had highest total PA, VPA and SED during the spring and summer months (all $p<0.05$). Furthermore, children had less TPA, LPA, MPA and MVPA, and more SED, during the autumn compared to the winter (all $p<0.05$). In the longitudinal sample, results were similar to the cross-sectional sample for the spring and summer months, with children having more TPA, VPA and MVPA during the spring and summer ($p<0.01$) compared to the other seasons. With regards to the autumn and winter seasons, results from the longitudinal sample shows the opposite trend as for the cross-sectional sample, with children having more TPA, VPA, MVPA, and SED in the autumn compared to the winter ($p<0.05$).

Moderators of physical activity

In the cross-sectional sample, there was no sex*age interaction for any of the PA variables or SED ($p=0.151$-0.750) (**Table S3 in Study I**). However, in the longitudinal sample, there was a significant interaction of sex*age for TPA, MPA, VPA, MVPA, and SED ($p=0.025$-0.048) (**Table 3**). TPA, MPA, VPA and MVPA increased in both boys and girls by age, yet boys had a relatively greater increase. Further, a different development in SED was found for boys and girls by age (positive trend in girls, negative in boys).

There was one significant interaction of age*season in the cross-sectional sample. MPA increased more by age during the winter compared to other seasons (p<0.05). No interactions of age*season were found in the longitudinal sample. Further, no interaction of sex*season was found in the cross-sectional sample; however, there was a significant interaction of sex*season in the longitudinal sample for LPA (p=0.026), MVPA (p=0.040), and SED (p=0.045). These results show a greater difference in MVPA between boys and girls during the winter and autumn than in the spring/summer, a smaller difference in LPA between boys and girls during winter compared to the other seasons, and greater differences in SED during the winter and spring/summer. Boys had consistently more PA and less SED compared to girls in all seasons (**Table 3**).

Furthermore, in the longitudinal sample we found a three-way interaction of sex*age*season for VPA (p=0.012) and MVPA (p=0.009). These results suggests that boys have a greater increase in VPA/MVPA by increasing age than girls during the spring and summer months relative to other seasons. Moreover, the youngest girls seem to have a relatively greater increase in VPA/MVPA during spring and summer months when compared to boys and older children (**Table 3**; **Figure 2 in Study I**). This interaction was not present in the cross-sectional sample.

Table 3. *Associations and interactions among physical activity, sedentary time, sex, age and season using repeated measurements (longitudinal sample).*

			Longitudinal sample (n = 330)					
			β (95 % CI)					
			Total PA	**SED**	**LPA**	**MPA**	**VPA**	**MVPA**
Main effects								
Sex (girls vs. boys)			-62.3 (-95.0, -29.6)**	19.9 (10.7, 27.3)**	-9.2 (-15.6, -2.9)**	-7.8 (-10.1, -5.4)**	-2.2 (-3.8, -0.6)**	-9.8 (-13.5, -6.2)**
Age (change per year)			58.2 (38.6, 77.8)**	-1.1 (-6.1, 3.8)	-7.5 (-11.4, -3.7)**	4.8 (3.4, 6.2)**	3.7 (2.8, 4.7)**	8.5 (6.4, 10.7)**
Season (ref. winter)		*Spring/summer*	163.7 (139.4, 188.0)**	1.2 (-5.0, 7.5)	-11.2 (-16.4, -5.9)**	-0.7 (-2.3, 0.9)	10.6 (9.4, 11.7)**	10.0 (7.7, 12.2)**
		Autumn	67.1 (43.8, 90.5)**	7.4 (1.4, 13.4)*	-14.5 (-19.6, -9.5)**	-0.1 (-1.5, 1.5)	6.9 (5.8, 8.0)**	6.8 (4.7, 9.0)**
Two-way interaction								
Sex*age			**p=0.044**	**p=0.043**	p=0.161	**p=0.048**	**p=0.030**	**p=0.025**
Age (change per year)		*Boys*	75.6 (45.5, 105.6)	-4.9 (-11.6, 1.9)	-5.8 (-10.8, -0.8)	6.1 (4.0, 8.2)	4.6 (3.2, 6.1)	10.7 (7.4, 14.1)
		Girls	31.4 (5.8, 57.0)	6.2 (-1.6, 14.0)	-11.2 (-17.5, -4.9)	2.7 (0.8, 4.6)	2.4 (1.2, 3.6)	5.2 (2.5, 7.9)
Age*season			p=0.876	p=0.391	p=0.345	p=0.106	p=0.165	p=0.833
Age (change per year)		*Winter*	61.9 (40.5, 83.3)	-5.9 (-13.9, 2.2)	-4.0 (-10.8, 2.7)	6.5 (4.5, 8.5)	3.4 (2.5, 4.2)	9.8 (7.3, 12.4)
		Spring/summer	61.1 (27.1, 95.1)	2.4 (-3.3, 8.1)	-10.4 (-14.6, -6.3)	3.8 (2.0, 5.6)	4.4 (2.8, 6.0)	8.2 (5.0, 11.4)
		Autumn	58.6 (34.7, 82.6)	0.1 (-5.6, 5.8)	-8.2 (-12.5, -4.0)	4.3 (2.6, 5.9)	4.0 (2.8, 5.2)	8.2 (5.5, 10.9)
Sex*season			p=0.094	**p=0.045**	**p=0.026**	p=0.137	p=0.088	**p=0.040**
Gender difference (ref. boys)		*Winter*	-62.7 (-97.4, -27.9)	12.0 (-1.1, 25.2)	-1.9 (-12.9, 9.1)	-7.5 (-10.8, -4.3)	-2.7 (-4.1, -1.3)	-10.3 (-14.4, -6.1)
		Spring/summer	-54.6 (-110.2, 1.1)	20.2 (10.9, 29.5)	-11.1 (-17.8, -4.4)	-7.3 (-10.2, -4.4)	-1.5 (-4.2, 1.1)	-8.8 (-13.9, -3.6)
		Autumn	-75.8 (-113.8, -37.8)	25.8 (16.7, 34.8)	-14.5 (-21.1, -7.8)	-8.6 (-11.2, -6.0)	-2.6 (-4.6, -0.7)	-11.1 (-15.3, -6.9)
Three-way-interaction								
Sex*age*season			p=0.066	p=0.429	p=0.251	p=0.085	**p=0.012**	**p=0.009**
Age (change per year)	Boys	*Winter*	65.3 (34.3, 96.3)	-8.9 (-19.4, 1.7)	-1.6 (-10.0, 6.8)	7.1 (4.1, 10.1)	3.3 (2.1, 4.6)	10.3 (6.5, 14.2)
		Spring/summer	92.5 (40.1, 144.8)	-1.8 (-9.7, 6.0)	-9.6 (-15.3, -4.0)	5.7 (3.2, 8.3)	6.2 (3.7, 8.7)	11.9 (7.2, 16.7)
		Autumn	63.5 (28.1, 98.9)	-1.1 (-8.7, 6.6)	-7.6 (-13.1, -2.1)	4.5 (2.0, 7.0)	4.2 (2.3, 6.1)	8.6 (4.5, 12.7)
	Girls	*Winter*	46.9 (16.3, 77.4)	3.4 (-9.7, 16.5)	-11.7 (-23.1, -0.2)	4.9 (2.2, 7.7)	3.5 (2.3, 4.8)	8.4 (5.0, 11.9)
		Spring/summer	9.7 (-35.0, 54.5)	10.2 (1.9, 18.4)	-12.8 (-19.3, -6.2)	0.7 (-1.7, 3.1)	1.7 (-0.3, 3.6)	2.2 (-1.7, 6.2)
		Autumn	42.6 (8.5, 76.7)	2.4 (-6.7, 11.5)	-8.4 (-15.3, -1.5)	3.2 (0.9, 5.5)	2.9 (1.3, 4.5)	6.1 (2.6, 9.7)

The β coefficient represents the difference in min spent sedentary (SED), in light physical activity (LPA), moderate physical activity (MPA), vigorous physical activity (VPA), and in moderate-to-vigorous physical activity (MVPA) and the difference in total physical activity (total PA) (cpm) compared to the reference category or as change per year. Final results from a three-level random intercept model adjusted for sex, age, BMI, parental education (highest level of mother or father), parental income level (highest yearly income of mother or father), season (winter: January-March; spring/summer: April-June; autumn: September-December), and accelerometer wear time (min per day), with random intercepts of “preschool” and ”child”. *p < 0.05, **p < 0.01.

4.2 STUDY II

Aims: To describe the distribution of PA and SED, during preschool hours vs. time out-of-care, and on weekdays vs. weekends (1), and to investigate differences in PA patterns across sex, age, and overall MVPA levels (2).

Sample description

Of 1308 study participants, 1109 (85%) children provided valid accelerometer data and were included in the analyses for **Study II** (**Table 1 in Study II**). Children's characteristics were similar to **Study I**.

Physical activity levels across settings and time of week

Children participated in more PA (all intensities) and less SED on weekdays compared to weekends (p<0.01) (**Table 4**). **Figure 4** illustrates how MVPA varied throughout an average weekdays and weekend days. There was a clear difference in pattern according to time of the week, with a peak of 7-8 min/hour at 1 pm and 3 pm on weekdays, compared to generally lower levels and a less characteristic pattern on weekends. When investigating the impact of preschool on children's PA levels, the specific preschool accounted for 5%–12% of the variance in children's PA and SED (ICC for full day/during preschool hours: TPA: 0.10/0.12; SED: 0.07/0.07; LPA: 0.12/0.12; MVPA: 0.05/0.06).

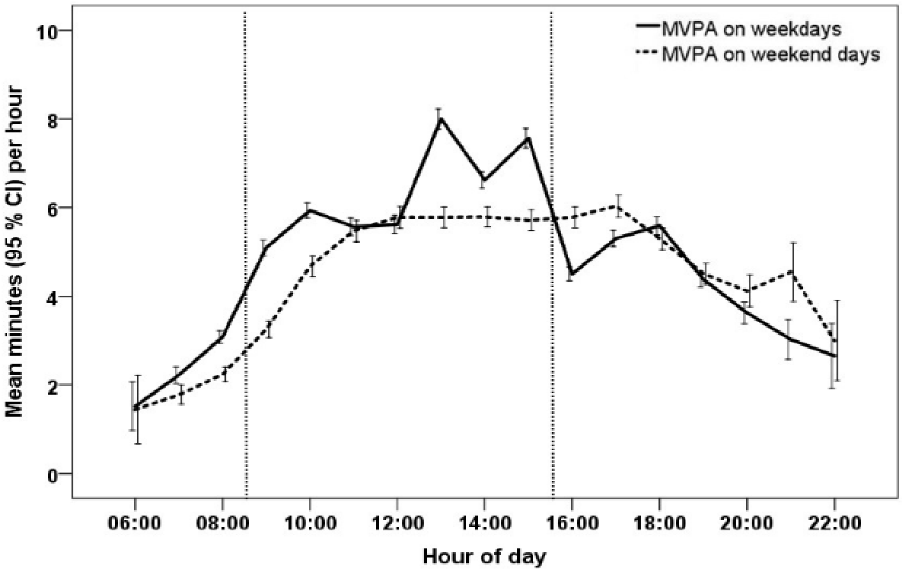

Figure 4. *Children's daily average moderate-to-vigorous physical activity (MVPA) per hour on weekdays (Monday-Friday) and weekend days (Saturday and Sunday). The vertical lines indicate 'preschool hours', defined as the hours between 08:30 am and 3:30 pm on weekdays.*

Most total PA and MVPA was accumulated during preschool hours, both in absolute values and when expressed relative to accelerometer wear time (i.e., time spent in the different settings). Boys and girls spent 12% and 10% of their preschool day in MVPA, respectively. Moreover, 77% of children's total MVPA on weekdays was undertaken during preschool hours. However, after adjusting for wear time, MVPA only differed significantly between preschool hours and time out-of-care among boys (p<0.05) (**Table 4**).

Table 4. *Mean values (SD) and differences (β, [95 % CI]) in wear time, SED, and time in PA between weekdays and weekends, and between preschool hours and time out-of-care*

	Time of week			**Setting**		
	Weekdays	Weekends	Difference adjusted for wear time	Preschool hours[a]	Time out-of-care[b]	Difference adjusted for wear time
	Mean (SD)		***β (95% CI)***	***Mean (SD)***		***β (95% CI)***
Total (n=1109)						
Wear time (min/day)	717 (44)	652 (66)	**65 (61, 69)****	407 (14)	163 (19)	**244 (243, 246)****
TPA (cpm)	753 (199)	719 (261)	**57 (39, 75)****	823 (240)	633 (225)	102 (-41, 244)
SED (min/day)	347 (55)	333 (63)	**-22 (-25, -18)****	179 (33)	91 (17)	-9 (-24, 7)
LPA (min/day)	298 (44)	257 (46)	**16 (13, 18)****	183 (29)	59 (11)	-1 (-13, 11)
MVPA (min/day)	68 (22)	59 (23)	**6 (5, 8)****	43 (15)	13 (5)	**8 (1, 15)***
Boys (n=572)						
Wear time (min/day)	720 (44)	659 (65)	**61 (56, 67****	407 (14)	164 (1)	**243 (241, 245)****
TPA (cpm)	787 (203)	748 (254)	**59 (34, 84)****	867 (255)	655 (16)	142 (-85, 369)
SED (min/day)	341 (54)	332 (60)	**-22 (-27, -18)****	172 (32)	91 (17)	-10 (-32, 13)
LPA (min/day)	301 (42)	260 (45)	**16 (13, 20)****	186 (28)	59 (11)	-4 (-20, 13)
MVPA (min/day)	74 (23)	64 (24)	**6 (4, 8)****	47 (16)	14 (5)	12 (1, 22)*
Girls (n=537)						
Wear time (min/day)	713 (43)	644 (67)	**70 (64, 75)****	407 (14)	162 (20)	**246 (244, 248)****
TPA (cpm)	718 (188)	689 (264)	**54 (28, 80)****	776 (213)	610 (212)	43 (-128, 214)
SED (min/day)	354 (50)	335 (66)	**-21 (-25, -16)****	186 (32)	91 (17)	-3 (-24, 18)
LPA (min/day)	293 (46)	253 (47)	**14 (11, 18)****	181 (30)	58 (11)	0 (-17, 17)
MVPA (min/day)	62 (20)	53 (21)	**6 (4, 8)****	39 (13)	12 (5)	2 (-7, 11)

[a]PS hours: Preschool hours (08:30 am–15:29 pm) on weekdays. [b]Time out-of-care (morning 06:00–08:29 am and afternoon 15:30–23:59 pm on weekdays). SD, Standard deviation. Unadjusted values are reported as mean (SD). The β coefficient represents the difference in wear time, min spent sedentary (SED), in light physical activity (LPA), and in moderate-to-vigorous physical activity (MVPA) per day, and the difference in total physical activity (TPA [cpm]), on weekdays vs. weekends and during preschool hours vs. time out-of-care. *p<0.05, ** p<0.01.

Table 5 gives an overview of the results on moderation of patterns across settings and time of week for sex, age, and overall MVPA levels. For the interaction of sex*setting (i.e., preschool hours vs. time out-of-care), preschool hours were associated with greater differences in TPA (p=0.013), SED, LPA, and MVPA (all p<0.001) between boys and girls relative to time spent out-of-care. Similarly, when testing the interaction sex*time of week (i.e., weekdays vs. weekends), we found greater sex-differences during weekdays compared to weekends, but only for LPA and SED (p=0.026 and 0.043, respectively). For the interaction of age*setting, the difference in MVPA and SED between preschool hours and time out of care was greater in older children, with relatively more MVPA and less SED during preschool hours by increasing age (p<0.001). Similarly, there was a significant interaction of age*time of week with greater difference MVPA (p<0.001) and SED (p=0.016) on weekdays than on weekends by increasing age.

Table 5. *Interactions between settings and time of week and SED and sex, age, and overall MVPA levels*

	N=1109, β (95% CI)			
	Total PA (cpm)	**SED**	**LPA**	**MVPA**
	Preschool hours vs. time out-of-care			
Sex*setting	**p=0.013**	**p<0.001**	**p<0.001**	**p<0.001**
Preschool				
Sex (girls vs. boys)	**-77.9 (-105.5, -50.2)****	**12.6 (8.9, 16.3)****	**-5.4 (-8.3, -2.5)****	**-7.3 (-9.0, -5.7)****
Time out-of-care				
Sex (girls vs. boys)	**-37.4 (-63.5, -11.2)****	**1.5 (0.1, 3.0)***	-0.1 (-1.2, 1.1)	**-1.4 (-2.0, -0.9)****
Age*setting	p=0.259	**p<0.001**	p=0.524	**p<0.001**
Preschool				
Change/year	**47.1 (30.5, 63.6)****	-1.9 (-4.1, 0.4)	**-3.1 (-4.8, -1.4)****	**5.1 (4.1, 6.1)****
Time out-of-care				
Change/year	**40.0 (23.7, 56.2)****	- 0.6 (-1.5, 0.3)	-0.7 (-1.4, 0.01)	**1.3 (1.0, 1.6)****
Total MVPA*setting	**p<0.001**	**p<0.001**	**p<0.001**	**p<0.001**
Preschool				
Change/min increase in MVPA	**9.2 (8.7, 9.7)****	**-1.0 (-1.1, -0.9)****	**0.3 (0.3, 0.4)****	**0.7 (0.6, 0.7)****
Time out of care				
Change/min increase in MVPA	**7.3 (6.7, 7.9)****	**-0.3 (-0.4, -0.3)****	**0.2 (0.1, 0.2)****	**0.2 (0.2, 0.2)****
	Weekdays vs. weekends			
Sex*time of week	**p=0.402**	**p=0.026**	**p=0.043**	**p=0.112**
Weekdays				
Sex (girl vs. boy)	**-57.4 (-80.0, -34.8)****	**15.1 (9.0, 21.1)****	**-5.2 (-10.0, -0.4)***	**-9.9 (-12.3, -7.5)****
Weekends				
Sex (girl vs. boy)	**-54.2 (-84.5, -23.9)****	**10.32 (4.0, 16.6)****	-1.3 (-6.2, 3.6)	**-8.8 (-11.4, -6.2)****
Age*time of week	**p=0.671**	**p=0.016**	**p=0.315**	**p<0.001**
Weekdays				
Change/year	**45.7 (30.7, 58.6)****	-2.6 (-6.3, 1.1)	**-4.8 (-7.8, -1.8)****	**7.6 (6.1, 9.1)****
Weekends				
Change/year	**44.4 (26.3, 62.5)****	1.4 (-2.4, 5.1)	**-6.5 (-9.4, -3.5)****	**5.6 (4.0, 7.1)****
Total MVPA*time of week	**p=0.089**	**p<0.001**	**p=0.016**	**p<0.001**
Weekdays				
Change/min increase in MVPA	**8.7 (8.4, 9.1)****	**-1.7 (-1.8, -1.6)****	**0.7 (0.5, 0.8)****	**1.0 (1.0, 1.1)****
Weekends				
Change/min increase in MVPA	**8.0 (7.3, 8.7)****	**-1.4 (-1.5, -1.2)****	**0.5 (0.4, 0.6)****	**0.9 (0.8, 0.9)****

Highlighted p-values are derived from interaction analysis. The β coefficient (95% CI) represents the difference in min per day spent sedentary (SED), in light physical activity (LPA), and in moderate-to-vigorous physical activity (MVPA), and the difference in total physical activity (cpm), compared to the reference category (girls vs. boys) or as a change (per year; per minute increase in overall MVPA), for the associated setting/time of week. Final results from a three-level random intercept model adjusted for sex, age, BMI, parental education (highest level of mother or father), parental income level (highest yearly income of mother or father), season, and accelerometer wear time. Overall MVPA: all day MVPA regardless of setting or time of week. *p<0.05, ** p<0.01.

4.3 STUDY III

Aim: To determine the intensity pattern associated with FMS in preschool-aged children using the whole PA intensity spectrum.

Children's characteristics

Of the 1308 participating children, 1081 (83%) children provided valid data of PA, FMS, and the included covariates and were included in the analyses for **Study III** (**Table 6; Table 1 in Study III**). Compared to children who provided valid data, those who did not (n=227) had parents with lower educational levels (p<0.05). The included and excluded children did not differ with regard to sex, age, BMI, or parental income levels.

The included children had a median of 13 valid days of PA registration (≤7 days: 5%; 8–11 days: 28%; ≥12 days: 67%). Age and sex related patterns of PA were similar as for **Study I and II**, although absolute PA values are different due to the application of 1- vs. 10-second epoch (**Table 6**). Further, boys scored significantly higher on object control skills than girls did (p<0.001), while girls scored better on locomotor and balance skills than boys did (p<0.001).

Table 6. *Children's average PA and FMS levels.*

	Total sample N=1081	**Boys n=555**	**Girls n=526**
Physical activity			
Wear time (min/day)	702 (50)	706 (50)	697 (49)
Total PA (cpm)	722 (197)	755 (197)	687 (190)
SED (min/day)	485 (42)	480 (42)	490 (41)
LPA (min/day)	142 (20)	147 (20)	137 (18)
MPA (min/day)	36 (7)	38 (7)	33 (6)
VPA (min/day)	35 (11)	38 (12)	33 (11)
MVPA (min/day)	71 (17)	75 (18)	66 (16)
≥60 min MVPA/day (%)	71	80	62
FMS			
Locomotor	1.3 (0.4)	1.3 (0.4)	1.3 (0.4)
Object control	1.2 (0.3)	1.3 (0.4)	1.1 (0.3)
Balance	1.4 (0.4)	1.4 (0.4)	1.5 (0.4)

Values reported mean ± SD, Standard deviation; FMS: Fundamental motor skills; possible mean score between 0-2 per domain (a mean score closer to 2 equals to more proficiency in the task or domain).

Bivariate correlations

Table 7 shows associations for intensity-specific PA (TPA, LPA, MPA, VPA, and MVPA) and SED with FMS. We found that TPA, MPA, VPA, and MVPA were positively associated with locomotor and object control skills (p<0.001). No associations were found with balance skills. The strongest association was found for VPA and MVPA with locomotor skills (r=0.26-0.27). Further, with reference to **Table 7**, FMS were not associated with LPA whereas SED was negatively associated with both locomotor and object control skills, but not with balance skills.

Table 7. *Correlations (Pearsons r) for physical activity (PA) intensities with fundamental motor skills (FMS)*

	Fundamental motor skills		
PA-variables	Locomotion	Object control	Balance
TPA (cpm)	0.23**	0.16**	0.04
SED (min/day)	-0.21**	-0.14**	-0.001
LPA (min/day)	0.05	0.03	-0.01
MPA (min/day)	0.20**	0.11**	0.03
VPA (min/day)	0.26**	0.18**	0.04
MVPA (min/day)	0.26**	0.16**	0.04

TPA: Total physical activity; SED: Sedentary time; LPA: Light physical activity; MPA: Moderate physical activity; VPA: Vigorous physical activity; MVPA: Moderate-to-vigorous physical activity. Models are adjusted for age, sex, parental socioeconomic status, season, test person FMS assessment, accelerometer wear time, BMI, and preschool. * p<0.05, ** p<0.001.

Multivariate pattern analyses

The association patterns for the PA spectrum were similar for the locomotor skill (R^2=9.7% for the vertical axis; 11.4% for all axes) and object control skill domains (R^2=3.9% for the vertical axis; 3.5% for all axes). For balance skills, a multivariate association pattern did not exist (result not shown as the model was not statistically significant). **Figure 5** illustrates the association pattern with locomotor skills for the PA intensity spectrum of the vertical (1), the antero-posterior (2), and medio-lateral (3) axis, respectively. PA intensity intervals between 5000 and 8000 cpm were most strongly related to locomotor and object control skills, whereas associations for lower and higher intensities gradually weakened. Time spent in 0-99 and 100-249 cpm was negatively associated with locomotor and object control skills. The association patterns were similar for boys and girls, and across age (median split, 50% youngest vs. 50% oldest) (r=0.82-0.98). The association patterns were strongest for the vertical axis for all outcomes, but otherwise fundamentally similar across the three axes.

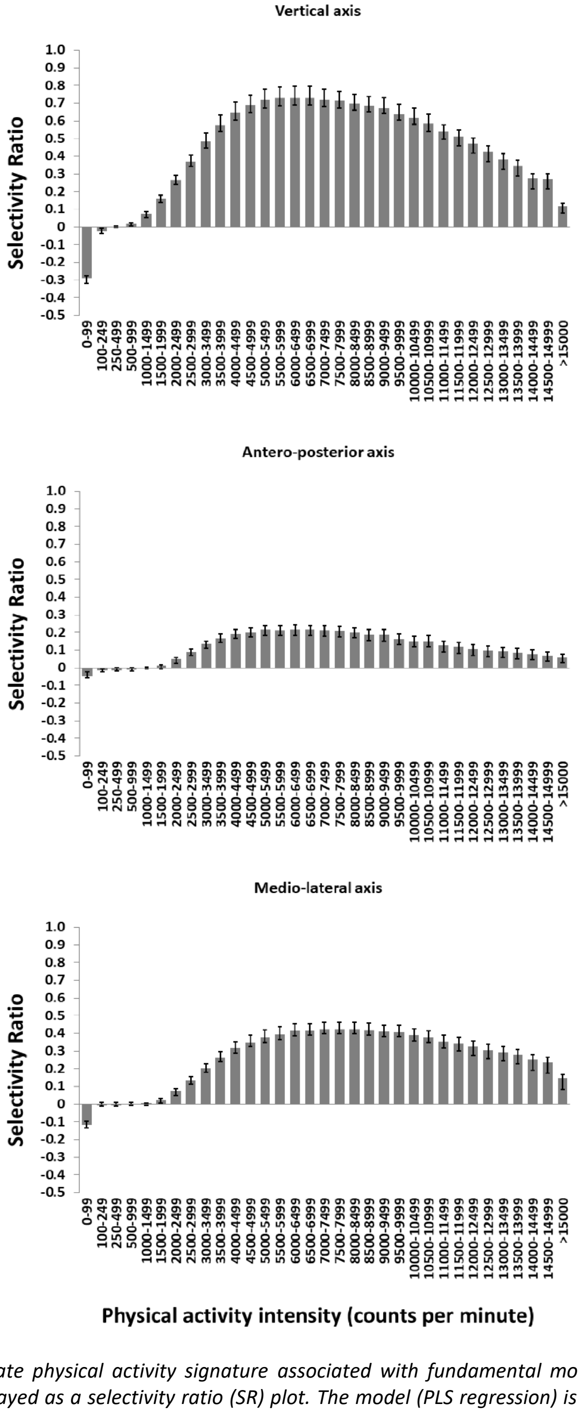

Figure 5. *The multivariate physical activity signature associated with fundamental motor skills (FMS) in the locomotor domain displayed as a selectivity ratio (SR) plot. The model (PLS regression) is adjusted for age, sex, body mass index, socioeconomic status, test person FMS testing, accelerometer wear time, and preschool. Locomotion skills: R^2 = 9.7% for the vertical axis only; 11.4% for all 3 axes combined. The SR is calculated as the ratio of explained to residual variance on the predictive (target projected) component. A positive bar implies that increased PA are associated with better skills within the locomotion domain.*

4.4 STUDY IV

Aim: Examine the prospective, bi-directional relationship between intensity-specific PA and domain-specific FMS in preschool-aged children over a period of two years.

Descriptives

Children's characteristics are presented in **Table 8**. All of the 376 children invited to the longitudinal part of PRESPAS participated in at least one measurement of PA at baseline, whereas 238 (63%) and 257 (68%) children had valid FMS and PA data, respectively, at both baseline and follow-up (n=292 children (78%) had valid PA data at all three time points during the baseline measurements). In total, 230 (61%) children provided valid PA and FMS data at both baseline and follow-up and were included in the analyses. Compared to the included children, excluded children (n=146) had parents with lower education and income levels (p<0.05), but were otherwise similar to the study sample.

Development in PA and FMS

The children had a median of 12 valid days of PA at both baseline and follow-up. Both PA and FMS levels changed significantly over two years (**Table 8**). Results show greater increase in TPA, MPA, VPA, and MVPA from baseline to follow-up in boys compared to girls (**Table S1 in Study IV**; **Figure 6**). For SED, the trends were opposite (**Table S1 in Study IV**). The development in PA was further strongly associated with age, with the younger children having a stronger, positive development in TPA, MPA, VPA, and MVPA, and a relatively smaller, positive development in SED, and smaller, negative development in LPA, when compared to the older children (**Table S1 in Study IV**; **Figure S1 in Study IV**; **Figure 6**). Concerning FMS, skills within all three domains improved over two years (**Table 8**). There was no difference in FMS development between boys and girls; however, increased age were associated with greater development in object control skills (**Table S2 in Study IV).**

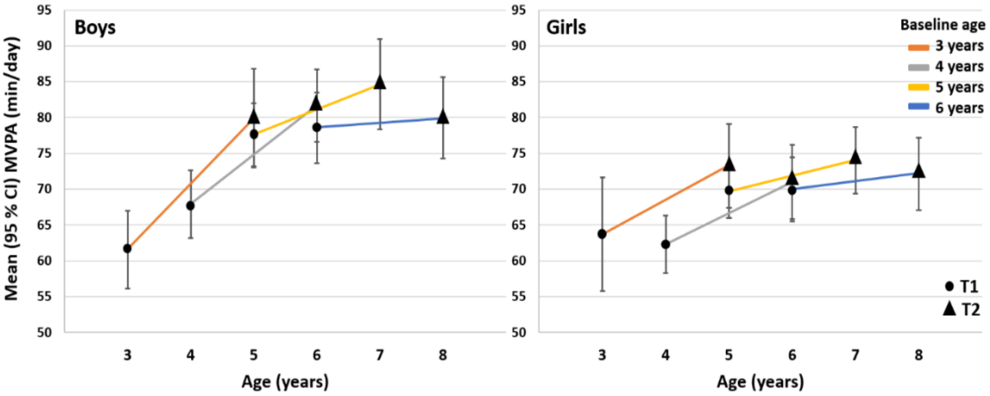

Figure 6. *Development in moderate-to-vigorous physical activity (MVPA) from baseline (T1) to follow-up (T2) in boys and girls by age.*

Table 8. *Children's characteristics at baseline and follow-up*

	n	Baseline 2015/2016	Follow-up 2017	Pearson's correlations	Change	P values [d]
Age (years)	*376*	4.7 (0.9)	6.4 (0.9)	--	--	--
Boys (%)	*376*	52 %	--	--	--	--
Anthropometrics	*249*					
Body height (cm)		109 (7.8)	121 (7.6)	0.962, *p<0.001*	12.0 (2.1)	*p<0.001*
Body mass (kg)		19.0 (3.2)	23.6 (4.3)	0.912, *p<0.001*	4.6 (1.9)	*p<0.001*
BMI (kg x m^2)		16.1 (1.3)	16.0 (1.7)	0.790, *p<0.001*	-0.1 (1.0)	*p=0.328*
Weight status[a] (%)						
Normal weight		84 %	85 %	--	--	--
Overweight		15 %	12 %	--	--	--
Obese		1 %	3 %	--	--	--
Fundamental motor skills[c]	*238*					
Locomotor skills		15.1 (4.4)	16.3 (4.0)	0.439, *p<0.001*	1.2 (4.5)	*p<0.001*
Object control skills		10.4 (2.9)	16.8 (2.9)	0.503, *p<0.001*	6.4 (2.9)	*p<0.001*
Balance skills		16.5 (4.9)	21.1 (3.4)	0.557, *p<0.001*	4.6 (4.2)	*p<0.001*
Physical activity	*257*					
Wear time (min/day)		692 (43)	724 (54)	0.495, *p<0.001*	32 (50)	*p<0.001*
SED (min/day)		474 (39)	503 (47)	0.616, *p<0.001*	29 (38)	*p<0.001*
TPA ([cpm])		722 (147)	741 (165)	0.522, *p<0.001*	19 (154)	*p=0.042*
LPA (min/day)		144 (16)	139 (18)	0.635, *p<0.001*	-5 (15)	*p<0.001*
MPA (min/day)		36 (6)	39 (8)	0.601, *p<0.001*	3 (6)	*p<0.001*
VPA (min/day)		34 (9)	39 (10)	0.580, *p<0.001*	5 (9)	*p<0.001*
MVPA (min/day)		70 (14)	77 (16)	0.610, *p<0.001*	7 (14)	*p<0.001*

All values are reported as means (standard deviations) unless stated otherwise. [a]Weight status according to Cole et al., 2000. [b]Score range: 0-2. [d] The change from baseline to follow-up was analysed with the use of a paired-sample T-test. *P*-values is statistic significant to the level of *p*<0.05. BMI: Body mass index; SED: Sedentary time; TPA: Total physical activity; cpm: counts per minute; LPA: Light physical activity; MPA: moderate physical activity; VPA: vigorous physical activity; MVPA: moderate-to-vigorous physical activity.

Prospective, bi-directional relationships between PA and FMS

TPA, MVPA, and VPA at baseline predicted higher locomotor, object control, and balance skills at follow-up (p<0.017) (**Table 9**). MPA predicted higher locomotor and balance skills at follow-up (p<0.032). SED predicted lower locomotor skills (p=0.012). LPA did not predict FMS at follow-up. We found no interactions with sex or age for the prospective relationship between PA (any intensity) or SED at baseline and FMS at follow-up (p=0.122-0.995).

When FMS were modelled as the exposure, and PA as the outcome, there was no prospective associations (**Table 10**). We found no interactions with sex or age for the prospective relationship between FMS at baseline and PA (any intensity) or SED at follow-up (p=0.055-0.957).

***Table 9**. Prospective associations (95 % CI) between physical activity at baseline (exposure) and fundamental motor skills at follow-up (outcome) (n=217)*

		Outcome at follow-up		
		Locomotor skills	**Object control skills**	**Balance skills**
Exposure at baseline	**TPA ([cpm])**	0.23 (0.07, 0.39) **p=0.006**	0.22 (0.07, 0.36) **p=0.004**	0.17 (0.03, 0.30) **p=0.014**
	SED	-0.27 (-0.47, -0.06) **p=0.012**	-0.19 (-0.38, -0.01) p=0.061	-0.14 (-0.32, 0.05) p=0.155
	LPA	0.10 (-0.04, 0.24) p=0.154	0.09 (-0.04, 0.21) p=0.192	0.09 (-0.04, 0.21) p=0.164
	MPA	0.22 (0.07, 0.37) **p=0.005**	0.13 (-0.01, 0.27) p=0.077	0.15 (0.03, 0.28) **p=0.032**
	VPA	0.25 (0.08, 0.41) **p=0.003**	0.19 (0.05, 0.34) **p=0.010**	0.20 (0.06, 0.33) **p=0.005**
	MVPA	0.26 (0.09, 0.42) **p=0.002**	0.18 (0.03, 0.33) **p=0.017**	0.19 (0.05, 0.33) **p=0.007**

All values are standardized β coefficients (95 % CI), analysed with a two-level linear mixed model. The models are adjusted for sex, baseline age, baseline body mass index, parental education- and income level, FMS assessor at baseline and at follow-up, baseline accelerometer wear time, and baseline value of the outcome. TPA: total physical activity; cpm: counts per minute; SED: sedentary behaviour; LPA: light physical activity; MPA: moderate physical activity; VPA: vigorous physical activity; MVPA: moderate-to-vigorous physical activity; FMS: fundamental motor skills. *P*-value in bold is statistic significant to the level of *P*<0.05.

***Table 10.** Prospective associations (95 % CI) between fundamental motor skills at baseline (exposure) and physical activity at follow-up (outcome) (n=224)*

		Outcome at follow-up					
		TPA ([cpm])	**SED**	**LPA**	**MPA**	**VPA**	**MVPA**
Exposure at baseline	**Locomotor skills**	0.06 (-0.08, 0.19) p=0.422	0.001 (-0.07, 0.07) p=0.989	-0.07 (-0.18, 0.05) p=0.239	-0.02 (-0.15, 0.11) p=0.734	0.06 (-0.08, 0.20) p=0.386	0.02 (-0.11, 0.15) p=0.706
	Object control skills	0.05 (-0.08, 0.17) p=0.472	0.01 (-0.06, 0.07) p=0.879	-0.08 (-0.19, 0.03) p=0.138	0.04 (-0.09, 0.16) p=0.557	0.06 (-0.07, 0.18) p=0.374	0.05 (-0.07, 0.17) p=0.385
	Balance skills	-0.06 (-0.19, 0.07) p=0.351	0.04 (-0.04, 0.11) p=0.348	-0.10 (-0.21, 0.02) p=0.114	-0.08 (-0.21, 0.05) p=0.214	-0.04 (-0.17, 0.09) p=0.532	-0.06 (-0.19, 0.06) p=0.308

All values are standardized β coefficients (95 % CI), analysed with a two-level linear mixed model. The models are adjusted for sex, baseline age, baseline body mass index, parental education- and income level, FMS assessor at baseline, accelerometer wear time at baseline and follow-up, and baseline value of the outcome. TPA: total physical activity; cpm: counts per minute; SED: sedentary behaviour; LPA: light physical activity; MPA: moderate physical activity; VPA: vigorous physical activity; MVPA: moderate-to-vigorous physical activity; FMS: fundamental motor skills. *P*-value in bold is statistic significant to the level of *P*<0.05.

5. GENERAL DISCUSSION

In the first part of the discussion, the main findings will be presented, and the results of the four individual studies will be integrated and discussed with reference to the headlines: '*Levels of physical activity among preschool aged children', 'The preschools role for physical activity', and 'The relationship between physical activity and fundamental motor skills'*. Thereafter, methodological considerations of accelerometer measured PA and assessment of FMS are addressed, followed by a discussion of general strengths and limitations of the thesis, and finally perspectives and suggestions for future research.

5.1 MAIN FINDINGS

Main findings from the four studies comprising this thesis are presented below.

In **Study I**, we showed that Norwegian preschoolers have similar PA levels as those found in other studies internationally, that boys were consistently more active and less sedentary than girls, and that PA increased with age for both sexes. Moreover, our findings suggest that boys exhibit a greater increase than girls in both TPA and MVPA with increased age. Additionally, PA differed across seasons, with higher levels of MVPA during the spring and summer than during the winter and autumn.

The findings from **Study II** showed that children spent more time in MVPA during preschool hours than during their time out-of-care. Similarly, children were more physically active and less sedentary on weekdays than on weekends. MVPA levels during preschool hours relative to time out-of-care were higher for boys, older children, and highly active children than for girls, younger children, and children with lower levels of overall MVPA (regardless of setting/time of week). Thus, with regard to MVPA, some groups of children appear to benefit more than others from the preschool arena.

In **Study III**, we determined the multivariate PA intensity signature associated with FMS. This novel approach showed for the first time how the whole intensity spectrum of PA associates with FMS in young children. The intensity profile associated with FMS was characterised by VPA, while weaker associations were found with lower intensities. The strongest associations were found for FMS within the locomotor domain, with weaker associations for object control skills. No association pattern was found for balance skills.

The findings from **Study IV** extends the current evidence regarding the relationship between PA and FMS by examining the prospective, bi-directional associations between intensity-specific PA and domain-specific FMS in young children. While baseline PA of at least moderate intensity predicted higher FMS at follow-up, baseline FMS were not predictive of future PA levels.

5.2 LEVELS OF PHYSICAL ACTIVITY AMONG PRESCHOOLERS

OVERALL PHYSICAL ACTIVITY LEVELS

Previous studies conducted in preschool-aged children have shown low levels of PA and high levels of SED, and correspondingly low compliance with MVPA recommendations (20, 23). In the comprehensive literature review by Bornstein et al. (20), the studies using ActiGraph accelerometers report that boys and girls on average accumulated 783 cpm and 696 cpm, respectively (20). These are comparable to our results for TPA (790 and 714 cpm, respectively), indicating that our sample of preschoolers has TPA levels similar to those in the international data.

When using the Evenson cut points (MVPA >2296 cpm) and 10-second epochs, we found that boys and girls accumulated an average of 72 and 59 minutes of MVPA per day, respectively (**Table 2**). This equals to a compliance with the 60 minute MVPA recommendation of 66% and 43% for boys and girls, respectively (**Table 2**). Among previous studies that use the Evenson cut points in preschoolers, the average time spent in MVPA ranged from 40-72 minutes per day and 32-62 minutes per day for boys and girls, respectively (195-198). Our findings correspond closely with the higher end of these ranges.

Dias et al. found that 79% of the children in their large cross-national comparison study met the MVPA guidelines based on MVPA >1680 cpm (133). If we compare the results from Dias et al. with ours using the Pate et al. cut points, we find our sample of preschoolers is more physically active with 95% compliance to the recommendations. Furthermore, a recent study by Ruiz et al. also applying the Pate cut points to analyse accelerometer data of 1131 preschoolers, reported the average time spent in MVPA per day to be 105 and 92 minutes for boys and girls, respectively. When we compare these numbers with our data analysed with the Pate et al. cut points, we find our children to be equally active (mean MVPA: 109 and 93, for boys and girls, respectively) (**Table S1 in Study I**).

Although comparisons between studies are problematic due to different data processing methods (e.g., different epoch settings), when compared to studies applying the same intensity thresholds, PA levels of Norwegian preschoolers seem to be fairly similar to those seen in other studies internationally.

PHYSICAL ACTIVITY BY SEX AND AGE

Limited research has targeted the development of PA during the years of preschool and early primary school. In the longitudinal analyses in **Study IV,** we found that younger children had stronger, positive development in both TPA, MPA, VPA, and MVPA (**Table S1 in Study IV**; **Figure 6**) over two years, compared to that of older children. Moreover, the younger children had a smaller, positive development in SED, and a smaller, negative development in LPA, than the older children (**Table S1 and Figure S1 in Study IV**).

There are few comparable longitudinal studies investigating development in PA with age in preschoolers, and the results of these are conflicting (144, 146-148). For example, a study of preschoolers in New Zealand found a decline in MVPA for both boys and girls between the ages three and four years (144), while others have shown an increase in TPA and MVPA with increased age (146-148, 180). This inconsistency could be explained by differences in the preschool environments' play opportunities, methodological discrepancies in processing of PA data, or cultural differences, for example related to school preparation among the older preschoolers, or the amount of outdoor time which is associated with higher levels of total PA and MVPA (24). Furthermore, our results show that younger children had considerably greater increase in PA of higher intensities over time, whereas the older children had a greater positive development in SED (**Study IV**). Moreover, when investigating development in PA by age we find almost no change in MVPA in the oldest children (≈8 years at follow-up) when compared to the other age groups (**Figure 6**). These results are in line with previous cross-sectional research (17), showing a peak in PA levels around the age of 5-6. Such findings are not surprising as the decline in PA is likely related to the transition from preschool to primary school, which is related to both environmental, social and behavioural changes, and thus opportunities for PA (17).

Reviews that have addressed correlates of preschool children's PA (67, 140) reports sex to be the most frequent individual correlate. Our results support this conclusion, showing consistently higher PA (and less SED) among boys than girls (**Study I-IV**). For example, boys obtained 13-16 minutes more of MVPA per day than girls did (**Table 2 and Table S1 for Study I**). This amount is similar to the reported sex difference in MVPA in the study by Ruiz et al. (135). Although the daily difference in MVPA between boys and girls is seemingly small, it translates to an additional ≈100 minutes per week, which could favourably affect health and should, therefore, be further assessed.

The observed increase in MVPA by age also seems to depend on the sex of the child. In the longitudinal analysis in **Study I** (10-month follow-up), we found a more pronounced increase in TPA, MPA, VPA and MVPA in boys than in girls over time. Results from **Study IV** supports this finding, providing more solid evidence through the two-year follow-up data. After adjustment of potential co-variates, being a boy predicted higher PA levels (both TPA, MPA, VPA, and MVPA) (e.g., 6.2 more minutes/day in MVPA than for girls) at follow-up (**Table S1 in Study IV**). Thus, not only are boys in general more physically active than girls (17, 67), but they also exhibit a greater increase in PA with increasing age.

Previous research highlight several possible explanations for why girls are less physically active than boys are. Several of these explanations are, however, not relevant to preschool-aged children and do not therefore explain the findings for this population – such as the fact that girls participate less in organised sport (199, 200) and may gain less enjoyment from taking part in physical education (201). Other possible explanations, that might apply to the preschool population, are that girls may receive less social support to engage in PA (202), that girls are observed to have less favourable individual attributes associated with PA (e.g., lower fitness and lower object control skills) (200), and that relationships between environmental correlates (physical and social) and PA may differ for boys and girls (203).

Biological reasons may also contribute to sex differences in PA, as such differences are consistent across countries (17). Furthermore, differences in PA levels between boys and girls have been shown to reduce after adjusting for sexual maturity (204), which suggests that lower PA levels in girls may be related to maturing at an earlier chronological age. Although we did find somewhat smaller sex-differences between the younger preschoolers in our study sample than among the older individuals (**Table 2**), we find this explanation questionable. Comparison of data from 9-10 year old Norwegian and American children shows that Norwegian 9-10 year-old girls were, on average, as active as American boys (658 vs. 655 cpm) (17). This finding suggests that the tendency of boys to be more active than girls does not imply that the PA levels of girls are 'low' in absolute terms.

Moreover, the age and sex differences in PA levels could partly be explained by differing PA patterns. For example, the study by Ruiz et al. suggests that there are age and sex differences in how children obtain their PA (135). While girls spend a greater proportion of their MVPA time in spurt-like MVPA patterns, boys spend a greater proportion of their MVPA time in sustained MVPA patterns (135). Ruiz et al. further found that each additional year of age was associated with less time in spurt-like activity and more time in sustained activity. These findings imply that boys and older preschoolers are active for longer periods of time (135). If such patterns persist as children age, these differences might, in part, explain the gap in MVPA between boys and girls through childhood and adolescence (17, 135).

SEASONAL VARIATION IN PHYSICAL ACTIVITY

In general, children's objectively measured MVPA tend to be lower in the winter than in the rest of the year (153). Furthermore, previous research suggests that preschoolers are more affected by season and weather conditions than older children and adolescents are (150). Previous research has also suggested that the seasonal patterns in children's PA are not necessarily present in all geographical areas, probably due to cultural and environmental differences (205). Our analyses from **Study I** show, however, that the PA levels of Norwegian preschoolers are strongly associated with season, with higher TPA, VPA, and MVPA and lower LPA and SED during the spring and summer than in the winter and autumn (**Table 3**). This finding is unsurprising, and it is also in line with observations of older Norwegian children and adolescents (206-208), given the great variation in weather conditions and daylight between seasons in Norway.

Moreover, in our sample of preschoolers, the PA pattern across seasons appeared to differ by age and sex. While no interaction was found between age and season for any of the PA variables or SED in the longitudinal sample, we did find an interaction of sex and season, with greater sex differences in MVPA during the winter and autumn than spring and summer. Furthermore, the oldest boys had the greatest development in MVPA from winter to spring/summer (**Figure 2 in Study I**). For girls, the reverse trend was observed, with the youngest having the greatest increase in MVPA from winter to spring/summer (**Figure 2 in Study I**). These results suggest that boys and girls across age have different seasonal patterns of MVPA. It seems that the oldest boys and the youngest girls increase their PA levels more during periods when it is easier to be highly physically active (i.e., spring/summer). This finding is difficult to explain, but we speculate that the spring and summer months, which are periods characterised by good weather and much daylight, provides more opportunities for outdoor play, which older boys – to a greater extent than girls – seem to exploit. At the same time, we speculate that the youngest girls (who are the least active) might be most restricted with regard to physically active outdoor play during winter and, thus, have the greatest potential to increase their PA levels to the spring/summer.

In **Study I**, there were inconsistencies between the results of the cross-sectional and longitudinal analyses with regards to seasonal variation in PA. Although the children in both samples accumulated most PA during the spring and summer months, seasonal variation in PA was different during the autumn and winter months in the two data sets. Furthermore, there was only one significant interaction in the cross-sectional sample (age*season for MPA), in contrast to significant interactions for both sex*age, sex*season and sex*age*season in the longitudinal sample (**Table 3**). These contradictory findings highlight the importance of repeated measures and within-subjects analyses when investigating age trends and seasonal variation in PA, which provide more reliable results than the use of single measurements, as children serve as their own control across measurements (209).

5.3 THE PRESCHOOLS' ROLE FOR PHYSICAL ACTIVITY

Social and physical environments have an important influence on child behaviour and development (154). Due to high attendance rates, preschools have a wide reach and can potentially provide opportunities for varied PA experiences for many children. Knowledge of where and when preschoolers are physically active is essential to make specific recommendations on how children can attain guideline amounts of PA. However, the literature is inconclusive on the importance of the preschool arena for children's PA levels, and whether children are, in fact, more physically active when in ECEC services.

Our findings (**Study II**) show higher activity levels during preschool hours than during time out-of-care, which is in line with three previous studies from the UK, Denmark, and Sweden (156, 160, 161), but in conflict with results from the USA and Australia (157, 162). The conflicting results could be explained by heterogeneity between samples, differences in preschool policies or environment, childcare attendance (e.g., hours per day in preschool), and/or the amount of time spent outdoors. As the results of the present study are in line with those from other north-western European countries, we suggest that differences in preschool policies and practices are key explanations for the conflicting results, although additional comparative studies are needed to make firm conclusions.

Another factor in the observed differences in setting-specific PA is the variability in preschool environments within the same country or geographical area, which can lead to inaccurate interpretations of the preschool's role for PA. In **Study II**, we found that the specific preschool explained 6% of the variance in MVPA and 12% of the variance in total PA accumulated during preschool hours. These percentages are in line with the median ICC (5%) reported in a systematic review by Finch et al. (210) and comparable with other European studies reporting on these specific variables (156, 211). In contrast, some American studies have shown that a specific preschool can account for up to 47% of the variance in children's PA (22, 184). Such variation might influence and possibly invalidate results from smaller studies, which will be strongly affected by random error and thus instable estimates. A low ICC, as seen for the studies involving European samples, may indicate that the included preschools are rather similar in terms of policies, practices, and environmental factors.

Our results (**Study II**) shows that the preschool arena is important for children's MVPA in two ways. The first factor is the actual time spent in MVPA during preschool hours, as these hours account for a large proportion of the child's week. We observed peaks in MVPA at around 1:00 pm and 3:00 pm on weekdays (**Figure 4**). In most of the preschools involved in PRESPAS, this corresponded closely with commonly scheduled outdoor time, which is associated with higher MVPA levels (24). Second, the preschool arena is also important in terms of the relative amounts of MVPA achieved when in preschool compared to time out-of-care, as MVPA levels – adjusted for time – are higher when children are in-care (although NS difference for girls) (**Table 4**). This suggests that attending preschool is favourable for young children's PA opportunities, although we are not able to compare PA levels in-care and out-of-care during the same hours on weekdays. Importantly, though, we found that boys undertook relatively more PA and less SED than girls when in preschool (e.g., a difference in MVPA for preschool hours vs. time out-of-care of 12 minutes for boys vs. 2 minutes for girls) (**Table 5**), suggesting that sex-differences in PA among preschoolers depend on setting. Our findings support those of Moller et al. and Hesketh et al., with boys exhibiting higher PA levels than girls when in preschool, although these studies did not test interactions relative to time out-of-care (156, 160).

Telford et al. conducted a study of 8-12 year-old children and found that the specific school attended explained variation in PA levels of boys (8.4%), but not girls. In our sample of children, the trend was opposite, with the specific preschool explaining 4% and 9% of the variance in MVPA among boys and girls, respectively. Such findings might indicate that there is a sex difference in the influence of the school/preschool on children's PA (200), which probably further depends on type of setting and/or the child's age. As proposed by Hesketh et al., we believe that the opportunities for high-intensity play in the preschool environment might suit boys better than girls due to their sex-related activity preferences (156). The Nordic preschool model is characterised by a focus on 'learning through play' and children spend a considerable amount of time outdoors (212). Therefore, we hypothesise that free outdoor play, in terms of MVPA, is more favourable to boys than to girls. Boys often prefer a more intensive, rough-and-tumble-play (213) pattern than girls, who tend to prefer social, often light-intensity play (214). Boys play patterns may vary less between the home and childcare environments, which could explain the observed sex differences in setting-specific PA. In contrast, Berglind and Tynelius found the reverse trend in their study of 4-year-old Swedish children. Their results show that differences between the sexes' respective PA levels were most apparent during time out-of-care on weekdays, with girls being relatively more active and less sedentary than boys when in preschool, and less active and more sedentary during time out-of-care (161). We find the conflicting results between the Swedish study and our results hard to explain.

To our knowledge, we are the first to investigate interactions of setting and time of week to age and overall MVPA levels within the preschool population (**Study II**). Despite relatively small differences, we found that the difference in MVPA and SED between preschool hours and time out-of-care was larger for older than for younger children, with relatively more MVPA and less SED when in preschool. These findings suggest that the age-related development in preschoolers' MVPA is linked more closely to factors within the preschool environment than to the out-of-care (i.e., home) environment. Furthermore, it appears that the preschool arena increasingly affects children's MVPA with increasing age, implying that older children (e.g., 5-6-year-olds) benefit more from this environment in terms of high-intensity activities than younger children do (e.g., 3-4-year-olds). Additionally, we investigated whether PA in different settings was dependent on children's overall levels of MVPA (regardless of setting/time of week), and found that children with higher levels of overall MVPA had more total PA and MVPA during preschool hours than time out-of-care, relative to children with lower levels of overall MVPA. These results suggest that highly active children undertake even more MVPA during preschool hours than children with lower overall MVPA levels. This finding is interesting as Moller et al. reported that less active children were substantially and consistently less active than highly active children, irrespective of context (160). However, Moller et al. did not investigate the relative difference in PA between children with high and low activity levels during preschool hours and time out-of-care.

5.4 THE RELATIONSHIP BETWEEN PHYSICAL ACTIVITY AND MOTOR SKILLS

INTENSITY AND DOMAIN SPESIFIC RELATIONSHIPS

Previous research have demonstrated a positive relationship between PA and FMS in childhood. Although this relationship might be obvious, less is known about the detailed intensity and domain specific associations between these variables. In **Study III**, we investigated the PA intensity signature associated with FMS using multivariate pattern analyses. This novel approach shows for the first time how the whole intensity spectrum of PA associates with FMS in preschool children. Our findings suggest that accumulated time in 5000-8000 cpm are strongest related to both locomotor and object control skills (**Figure 5**). Although weaker associations were found for intensities in the light (≈100-2500 cpm) and moderate (≈2500–4000 cpm) range (97), the association pattern was clearly dominated by intensities in the upper vigorous range (e.g., activities involving running, jumping, chasing etc.). Thus, this intensity-range could be a relevant target for future studies investigating associations with FMS, if not using the whole intensity spectrum.

Our results correspond well with most previous findings. MVPA and VPA are commonly associated with FMS (164, 167, 169-172, 178, 215, 216), whereas the few studies that have investigated LPA show inconsistent results. Some studies report no relationship between LPA and FMS (171, 172, 174, 178), while others show positive associations (169, 216). In our detailed analyses, we found that although PA within the typical LPA range was associated with FMS (locomotion and object control skills), the relationships were weaker than for higher intensities. Few studies have investigated the association between SED and FMS; though some studies have indicated that lower SED is associated with better FMS (171, 174, 175). We hypothesised and confirmed a negative relationship between SED and FMS, as previously shown by Lopes et al. (175). As displacing SED inevitably means introducing PA (173), we would expect the reverse trend for FMS and SED compared to PA, which was confirmed for both domains where an association was evident (i.e., locomotor and object control skills).

As expected, our findings from **Study III** are consistent with evidence that FMS are strongly and positively related to age, and that boys perform better in object control skills, while girls perform better in balance skills (167). In our sample, girls also scored higher on locomotor skills, which is in line with the results of Cliff et al. (182). These findings may be explained by the variation in the types of activities practiced, with boys tending to prefer ball games, including throwing, catching and kicking, and girls opting for light physical activities that demand focus and stability. This suggests that object-control skills relate most closely to boys' habitual PA, and balance to girls’ PA. The difference in locomotor skills is, however, less obvious. Although the actual level of PA and competence in the domain specific

FMS scores varied between the sexes and increased by age, there was no difference in the association patterns between boys and girls, or between 50% oldest vs. youngest children in our sample.

We find it plausible that different PA intensities have different associations with various domains of FMS, as they may represent different types of activities (167). Skills within the locomotor domain are typically needed during activities that requires high intensity (i.e., running, jumping, etc.), and high participation in these activities would likely be associated with better locomotor skills. Furthermore, while locomotor skills involve moving the body through space, they are often also utilised in activities that involves object control skills (e.g., ball games). Therefore, it is natural that these types of skills are highly associated with VPA, while the mechanisms behind the development of balance skills might have other characteristics that are not well captured by accelerometry. Moreover, Gallahue et al. (2012) classify FMS within three distinct holistic domains (locomotion, object control, and balance skills) and state that there are typical developmental progressions between skills and between the domains. They surmise that children need to master certain balance skills before they can progress onto locomotor skills and that children seem to form balance and locomotor skills earlier than they develop object control skills (44). Thus, balance skills might be seen as underlying abilities for locomotor skills (166). These perspectives provide a plausible explanation to our null findings regarding the associations between PA and balance skills.

Analysis by Williams et al. has previously suggested that locomotor skills might relate more strongly than object control skills to objectively measured PA in four-year-old children (171). This could be explained by the accelerometer placement (hip), which is limited in its ability to capture upper body movement, for example, when throwing or catching a ball (97). Thus, the intensity of the execution of object control activities is likely underestimated when measured with an accelerometer (217). This limitation might lead to somewhat weaker associations for object control skills than for locomotor skills, at least when applying only the vertical axis. Our findings show, however, that uniaxial and triaxial accelerometry provided similar information regarding the cross-sectional relationship between PA and FMS.

LONGITUDINAL, BI-DIRECTIONAL RELATIONSHIPS

As expected, FMS improved over the two-year follow-up period (**Study IV**). The younger children had a greater increase in object control skills than the older children did, which makes sense as such skills are more advanced than locomotor and balance skills (44), and likely to improve at a later stage of development (i.e., normally by age). While previous studies have suggested that boys develop certain gross motor skills earlier than girls do (218, 219), we observed no sex differences in the development of FMS.

The findings from **Study IV** extend the current evidence regarding the relationship between PA and FMS by examining the prospective, bi-directional associations between intensity-specific PA and domain-specific FMS in young children. We found that children who engaged in more MVPA and VPA during their preschool years performed better in FMS' (all domains) two years later. Moreover, MPA predicted locomotor and balance skills. These findings are consistent with the few previous studies that have examined prospective associations between PA and FMS in children (180, 181). Similar to Lima et al., we found that associations were strongest for VPA (181), which is in line with our cross-sectional findings in **Study III**. Furthermore, there was a negative, prospective association between baseline SED and locomotor skills at follow-up. LPA at baseline did not predict any FMS variable at follow-up.

Based on our results, for each additional SD in MVPA (≈15 minutes), the locomotor skill score increased by 0.26 SDs. In comparison, Lima et al. found that locomotor/dynamic balance skills increased by 0.14 SD for each additional SD in MVPA (181). Because others have found a bi-directional relationship between PA and FMS in older children (181), and because small improvements in FMS may enhance physically active play opportunities, we regard this increase as meaningful for children's future FMS and PA development. Therefore, in line with Barnett et al. (180), our findings show the importance of MVPA during the preschool years for FMS development.

Contrary to the findings above, we did not observe any prospective associations between FMS at baseline and PA at follow-up. One would expect motor-competent children to experience greater success and enjoyment during physically active play and therefore to participate in more PA (166). Thus, the lack of prospective associations between FMS (predictor) and MVPA (outcome) conflicts with previous findings (147, 177-179, 181). However, the null findings could be explained by the great development in FMS that occurs during the preschool and early school years (44). Since FMS improves substantially over two years in young children (67, 147, 180), it may be reasonable to believe that the current skill level could be more strongly related to MVPA than previous skill level (as demonstrated for the current sample, **Study III and IV**). A direct comparison of our results with previous studies is difficult, however, due to differences in follow-up duration, age of participants, and different assessment methods for FMS. Nevertheless, it is likely that FMS proficiency plays a causal role in determining PA behaviour at a later stage of child development.

Studies comparing the relationship between FMS and PA among boys and girls draw inconsistent conclusions: some indicate similar cross-sectional relationships (171, 174), while others suggest a stronger relationship among boys (182, 220). Comparisons between studies are made difficult by methodological heterogeneity, particularly in FMS measures, but our null findings regarding sex-interactions suggest similar prospective relationships in boys and girls.

Our findings support the hypothesis of Stodden et al., in that the association between PA and FMS could be the reverse for young children of that for older children and adolescents (166). Our findings suggest prior time spent in MVPA is more relevant for current level of FMS than prior FMS level is for current amount of MVPA when children are between the ages of 5 and 8. Stodden and colleagues also hypothesise that the relationships between FMS and PA strengthen as children age and develop (166). Therefore, we would expect interactions of age for the prospective associations between PA and FMS. However, no such interactions were present in our material. It should be kept in mind, though, that the lack of interactions could result from the narrow age span of the included children. Importantly, as previous evidence is primarily derived from older children, more longitudinal studies starting at an early age, and with longer follow-up durations are needed to investigate the moderating effect of age on the bi-directional relationship between PA and FMS.

5.5 METHODOLOGICAL CONSIDERATIONS

ACCELEROMETRY

Accelerometers are advantageous for minimising researcher and participant reporting bias, and enables objective measures of PA in large study samples. However, as addressed in the background section, accelerometers are not without their limitations. When using accelerometers to assess PA, particularly in young children, we are faced with a wide variety of protocols and data reduction procedures, making methodological decisions and subsequent comparison between studies difficult.

The main PA outcomes in PRESPAS were based on the Evenson et al. cut points (97) (MVPA ≥ 2296 cpm) as recommended for children in general by Trost et al. (99). However, due to the ongoing debate on which accelerometer cut points that accurately reflect the various intensities of PA among preschool-aged children, we chose to analyse our cross-sectional data in **Study I** with an extra set of cut points proposed by Pate et al. (74) (MVPA $\geq$1680 cpm)(**Table S1 for Study I**).

Both the Evenson and Pate cut points are widely used in preschool populations (86), although the Evenson cut points are only validated for children from the age of five years. It is important to note that cut points validated in a specific age group might not be valid for other age groups, and it has therefore been argued that these criteria should be age-specific (86). Although we applied two sets of widely used cut points for children in PRESPAS, we did not include age-specific cut points herein. Our findings of increased PA levels by age presented in **Study I** (with 25% of the three-year-olds achieving the MVPA guideline compared to 72% of the six-year-olds) when using the Evenson cut points (**Table 2**), are therefore somewhat challenging. If young children should have age-specific cut points due to differences in energy consumption and effort related to movement, these results might be biased.

Furthermore, as children have a rather sporadic PA pattern, with bouts of PA generally lasting <10 seconds (100-103), shorter epochs are recommended – rather than the traditional 60-second intervals – to accurately capture PA (72). Therefore, we used 10-second (**Study I and II**) and 1-second (**Study III and IV**) epochs to avoid loss of information and misclassification of PA intensity (i.e., overestimation of LPA, and underestimation of SED and VPA) in PRESPAS. However, because the choice of cut points and epoch length has a major impact on the amount of acceleration (i.e., movement) that is classified as MVPA, it is challenging to report on the findings for exact amounts of MVPA accumulated and compliance with the intensity-specific guidelines. Depending on the cut points applied (Evenson or Pate), we found that 55-95% of the children achieved the guideline amount of 60 minutes MVPA per day using 10-second epochs (**Table 2; Table S1 for Study I**). Moreover, when we compare the descriptive results on PA levels using the Evenson cut points with 10- and 1-second epochs, we find that children engaged in 66 and 71 minutes of MVPA per day, and had compliance levels of 55% and 71% for the MVPA guidelines, respectively (**Table 2**; **Table 8**). This variability poses significant challenges to our understanding of PA levels of young children and to the communication of results regarding compliance with PA guidelines. However, using 1-second epochs possibly provide more accurate information regarding the amount of VPA accumulated. Thus, the compliance level of 71% might be a better estimate of 'true' PA levels. Furthermore, in our sample, the strength of the associations between VPA and FMS slightly increased when applying 1- vs. 10-second epochs (results not shown). Thus, we consider 1-second epochs to capture more relevant information about the children's VPA in relation to FMS when compared to 10-second epochs. This finding is similar to what is previously shown for older children in relation to cardio metabolic health (221).

In PRESPAS, as in most studies using free-living accelerometry monitoring protocols, the children were asked to remove the accelerometers during water-based activities (e.g., swimming or showering) and when sleeping (at night). As sleep-related behaviours were not a study aim for PRESPAS, we chose a waking-hours protocol instead of a 24-hour protocol to reduce the participant burden. However, this could lead individuals to forget to wear the accelerometer for a period of time. In PRESPAS, we chose to define periods of ≥ 20 minutes of zero counts as non-wear time, as proposed by Esliger et al. (187). Based on evidence showing that eight hours per day wear time provides reliable results (35), and with the age of the children taken into account, we used a minimum of 480 wear minutes to define a valid day in PRESPAS (i.e., a minimum of eight hours). Furthermore, we used an *a priori* defined minimum of four valid days as an inclusion criterion, as suggested previously (86, 106). However, due to the considerable week-by-week variability observed when measuring PA using accelerometers in preschool-aged children (35), a long registration period (> 7 days) was applied to increase the reliability of the accelerometer measurements (35) and, thus, increase the reliability, reduce measurement error, and improve the validity of the study conclusions. Therefore, we used a 14-day protocol of PA monitoring rather than the traditional seven days (median: 12–13 days of valid PA data across **Study I–IV**).

In addition to challenges relating to cut points, epoch length, wear time, and other methodological considerations, the accelerometer does not correctly classify intensity in certain activities (e.g., cycling). Furthermore, it does not provide information about the type of PA or the context in which the PA is conducted, which would have been valuable information when studying PA patterns in different settings and in relation to FMS development. In addition, it is well known that ActiGraph counts level-off for high-intensity activities, such as running (222, 223), and thus underestimates VPA. This could be the reason for the observed attenuated relationship between high intensity PA and FMS in **Study III**.

Thus, the inverted-U pattern for the association between PA and FMS illustrated in **Figure 5**, showing attenuated associations ≥ 8000 cpm, is likely to be a spurious finding. As such, accelerometers do not provide a perfect measure of true SED time or very high PA intensities (72). Our findings should therefore be considered with limited classification accuracy of PA intensity, and posture allocation, taken into account.

The majority of studies using accelerometry in preschool children apply the vertical axis only (224), as vertical ambulatory movements or movements of the trunk generate the most PA-related energy expenditure (78). However, it has been hypothesised that triaxial accelerometry, permitting the measurement of movements in the anteroposterior axis (forwards and backwards movement) and in the mediolateral axis (side to side movement), may better capture free-living daily activities (225-229). Recently, Aadland et al. (230) showed that triaxial accelerometry and multivariate pattern analysis have the potential to capture and model considerably more information about children's PA – of relevance to health – than using uniaxial accelerometry alone. Specifically, while the use of the vertical axis only resulted in an explained variance of 17% in association to a cardiometabolic composite score, the use of all axes in one joint model increased explained variance to 30%. In **Study III**, we therefore applied triaxial data to investigate whether the inclusion of three axes vs. one axis revealed stronger associations between PA and FMS. Our findings showed, however, that uniaxial and triaxial accelerometry provided similar information regarding the cross-sectional relationship between PA and FMS. Thus, although triaxial accelerometry may have potential to capture important aspects of children's PA, our findings do not support this hypothesis with regard to FMS skills in preschoolers.

Great care should be taken when interpreting the PA levels of preschoolers to inform policy decisions, such as the development of PA guidelines. Hence, considerable attention is required to unify accelerometer-derived MVPA so that unbiased comparisons across studies can be made.

MOTOR SKILL ASSESSMENT

FMS are considered the 'building blocks' of the more advanced complex movements that are conceptualised, operationalised, and measured in different ways across studies (231). Thus, FMS is difficult both to define and hard to measure accurately. Many different test batteries for FMS evaluation exist, and there is no established 'gold standard' of assessment of FMS in children (117). In PRESPAS, we constructed a test battery inspired by the recognised TGMD-3 (113) and the PGMQS (120) because we wanted a process-oriented tool providing information on the qualitative aspects of movement, that included balance skills, and were feasible to measure a large study sample. Moreover, as we wanted to follow children over time, we needed a tool that was validated for children aged 3-8 years. According to the author, TGMD-3 is suitable for the purpose of assessing changes as a function of increasing age (113).

An advantage of process-oriented vs. product-oriented methods, is the incorporation of qualitative aspects in the assessment providing more information, and thus, are more sensitive in detecting specific skills than a product-oriented test (108). As stated by Stodden et al. product scores has *'[…]no relationship to the child's motor development or ability to apply a motor skill to the real world of physical activity'*(166). Moreover, a high score on a product-oriented test might tell us more about the child's fitness level than his or her ability to perform a movement with accuracy and control. A study by Rudd et al. examined the relationship between the TGMD-2 (process) and the KTK (product) test (232), and found that these two assessment tools measure discrete aspects of FMS. The results from this study suggests that both object control and locomotor skills from the TGMD-battery and the locomotor/dynamic balance skills of the KTK are related to the overall concept of FMS (232). Thus, if feasible, studies should include both process- and product-oriented tests across several domains of FMS to obtain a more holistic picture of FMS (232).

Based on the comparisons of tools made by Cools et al. and Logan et al. (107, 108), we deemed the inclusion of items from the TGMD-3 in our FMS assessment to be appropriate for the use in PRESPAS. Although the TGMD were originally developed to identify developmental delays (107), the authors state that the TGMD-3 can also be used to measure normally developing children and to investigate relationships between FMS and other health-related factors (113). However, the TGMD-3 was developed in the USA and contains particular movement tasks that are less culturally relevant in Norway (e.g., the baseball strike and bouncing a ball). Thus, as highlighted by Cools et al., the TGDM-3 needs adaptation to fit a European context (108). Furthermore, the full version of the TGMD-3 (13 items) is time-consuming to implement, and the test battery does not contain balance tasks, which we considered a limitation. To measure FMS in a large study sample and, at the same time, cover the three recognised domains of FMS (44) – and such provide a holistic picture of FMS – we choose to modify and extend the TGMD-3. We did so by reducing the number of skills tested and by including three balance items proposed by Sun et al. (120). This way, we were able to better suit our study aims and context and to reduce the participant and researcher burden.

TGMD-3 has the advantage of including both a qualitative, criterion-referenced evaluation of the skills and quantification of the results (108). However, results from the investigation by Logan and colleagues indicate that the sensitivity to detect advanced skill levels might be lower for the TGMD tool when compared to other tools with several evaluation criteria' that provide a more nuanced description of skill levels (e.g., the Get Skilled, Get Active (115)) (107). Another limitation of our assessment is the possible ceiling effect in the follow-up sample. According to the normed values, it is clear that as children reach the age of 10, the scoring levels out towards maximum values (113). However, ceiling effects are a limitation of many qualitative assessments (107), in contrast to product-oriented assessments, which report results as continuous variables. Nevertheless, our results show that there was still variation in the FMS scores at follow-up; thus, we believe that the criteria' used were developmentally appropriate and sufficiently sensitive for our sample.

When studying FMS in large samples, with several evaluators involved in the assessment, methodological challenges concerning inter-rater reliability are highly relevant. Such challenges are in particular present when using process-oriented test batteries to evaluate FMS (compared with product-oriented batteries that provide more 'objective' results), as test batteries with a higher degree of subjective evaluation of the performance are more exposed to bias. Thus, a high inter-rater reliability score is important for the validity of the TGMD-3/PGMQ assessment. Prior to the data collection in PRESPAS, all assessors were thoroughly trained in how to instruct and score children in the different movement tasks, and the inter-rater reliability (ICC) was high for all FMS domains (0.74 - 0.90) prior to testing, which is a strength of the study.

As explained in the methods section, we used the original procedure of TGMD-3 and PGMQ when evaluating the children. For **Study IV** we used the original domain sum scores, however, for **Study III** we chose to apply an average score. Although different to the original scoring, we argue that a mean score is meaningful because it is independent of the number of criteria for each skill. As the TGMD-3 battery is considerably modified in PRESPAS (six items), reporting similar domain sum scores might be misleading – as the score level would be much lower than when completing the whole TGMD-3 test (13 items). Moreover, since we included the three balance items, a potential sum-score across domains is not comparable to other studies using the TGMD-3. Nevertheless, sensitivity analysis using sum/mean domain scores in the analysis for **Study III and IV** provided the same conclusions (results not shown), thus our results are not considerably affected by the choice of scoring procedure.

Because of the considerable modification of the TGMD-3, our results are limited by a lack of comparability with other studies using this battery. However, the purpose of **Study III** and **IV** was to determine the PA intensity pattern associated with FMS in preschool-aged children and to investigate the prospective associations between PA and FMS – not to identify children with high or low FMS levels or developmental disorders. Although we agree that it would have been relevant and interesting to make comparisons between the PRESPAS material and that of others on FMS levels among young children, we are not able to do so on a domain-level due to our methodological choices. However, we have included raw item scores as a supplement (**Table S5 for Study IV**).

5.6 GENERAL STRENGHTS AND LIMITATIONS

GENERAL STRENGHTS

This is the first large-scale population-based study to describe objectively measured PA levels of Norwegian preschoolers. In addition to the large cross-sectional sample, the major strengths of the studies included in this thesis are the wide age range of preschoolers, the relatively high response rate, the exceptionally good compliance with the accelerometer protocol, the long PA-monitoring period, and the two-year follow-up time for our longitudinal sample. We accounted for several potential covariates (sex, age, BMI, parental income and education level, season, accelerometer wear time, and assessor for FMS testing) to limit confounding. Furthermore, by including the random effect of preschool in the analyses of associations and interactions between PA and potential correlates, we took in to account the possible cluster effect of preschool on our results.

The prospective design used in **Study IV** with a follow-up time of two years is relatively long when compared to the majority of previous studies, especially considering the children's young age. We further consider the measurements of both PA and FMS at two time points, which allowed for analyses of these variables' reciprocal relationships, a major strength of **Study IV**. Importantly, this protocol provided stronger prospective evidence than some previous studies that were not able to adjust for baseline levels of the outcome when investigating prospective relationships (147, 177, 180). Thus, our results allow for rather strong inference of causality, although residual confounding cannot be excluded. Additionally, the multiple PA measurements used as the baseline (i.e., a mean of three 14-day PA measurements), provides a solid foundation for investigating the focused relationships.

In **Study III**, we used multivariate pattern analyses to solve the collinearity challenge and explore the PA intensity pattern associated with FMS. Multivariate pattern analyses are widely applied in pharmaceutical (191) and metabolomics studies (233). Aadland et al. recently used this approach to determine the PA intensity signature associated with metabolic health in schoolchildren (62). Multivariate pattern analysis can handle completely collinear variables (62, 191, 234, 235), and it is therefore well suited to studying associations for strongly correlated accelerometry data. Because this method allows for a more integrated and valid interpretation of findings, it is a promising approach in the field of PA epidemiology (62). Thus, the simultaneous modelling of the whole intensity spectrum of PA applied in **Study III**, without the use of pre-defined accelerometer cut points – is a major strength when investigating the relationship between PA and FMS. As previously called for (9, 167, 173), a much more nuanced picture of the associations between PA and FMS was provided than previously documented by using the whole intensity spectrum.

GENERAL LIMITATIONS

The participating children were recruited through their preschools, which led to the exclusion of children not attending preschool at the time. However, as the preschool attendance rate in Norway is very high, only a small proportion of the population of interest (≈ 3%) was excluded based on this recruitment strategy. The average parental educational level among the included children was higher than that among the excluded children in most analyses and slightly higher than the average level for Sogn og Fjordane county (236). Furthermore, our sample was highly homogenous in terms of ethnicity and geography. This means that the current study, despite its large sample and relatively high response rate, might be exposed to selection bias. The results should therefore only be generalised with caution to ethnic minority populations or those with lower SES.

Regarding seasonal variation in PA addressed in **Study I**, these analyses are limited by the lack of weather and temperature data, which may lead to an attenuation of associations to PA if the weather during the registration period were atypical for the season. Another limitation that applies to **Study II** is the use of standardised times for defining periods in and out of preschool, which might have introduced some misclassification of time use. However, although some random errors may have been introduced, estimates were based on the means of attendance; thus, we consider that the results were not biased through our choice of time categories.

The results from **Study IV** also need to be interpreted with some limitations in mind. It is possible that the null finding in terms of FMS being a predictor of future PA could be influenced by different degrees of measurement errors in the PA and FMS variables and, thus, sensitivity in the measurement methods. Because the PA assessment at baseline consisted of up to six weeks of objective PA registration, which may have provided a more precise estimate of PA than the single FMS assessment (at both time points), the results could be subject to differing measurement errors and differing regression dilution bias. When the more imprecise variable is modelled as the outcome, the magnitude of the effect is estimated accurately, but with wider confidence intervals. In contrast, when the more imprecise variable is modelled as the exposure, this tends to attenuate the regression coefficient (209). Also, a considerable number of children (n=159 and n=152 for the prospective, bi-directional analysis presented in **Table 9 and 10**, respectively) were excluded from the main analyses because of missing data in either predictors, outcomes, or co-variates at baseline or follow-up. However, differences between included and excluded children were minor at baseline. Finally, our study sample consisted of healthy children without known disabilities that could affect PA levels or FMS performance. Thus, caution should be exercised when generalising the results from **Study III and IV** to populations of children with developmental delays or motor impairment.

5.7 PERSPECTIVES AND FUTURE RESEARCH

The preschool years is a critical period in which to lay the foundation for sufficient PA levels throughout childhood (31). The findings provided through this doctoral thesis suggests that there is a potential to increase MVPA levels among Norwegian preschoolers.

Previous studies have highlighted the home environment as an important arena for PA promotion in preschool-aged children, as this arena seems to have great potential to increase MVPA levels (156, 160, 161). Lower PA levels at home than during preschool hours, as shown in **Study II**, are consistent with this view. However, although we recognise the home environment as a highly relevant arena for young children's PA, we consider the preschool to be an ideal setting for promotion of structured PA for all children, irrespective of their characteristics, parents' behaviours, attitudes and resources. The preschool arena is important for children's MVPA. However, our findings from **Study II** indicate that this environment stimulates boys, older children, and highly active children more successfully in terms of higher MVPA levels, which suggest that increased awareness of the preschools' role in promoting PA for all children could contribute to reduce the observed differences in PA between boys and girls.

The measurement challenges discussed above impedes our ability to generate the 'true' PA levels of our study sample. However, although the communication of the exact levels of accelerometer-derived PA is challenging, it is important to keep in mind that the relevance of studying PA in children extends beyond establishing whether the recommended daily level is achieved. Investigation of PA patterns benefits our understanding of how PA varies among groups of children and who is more likely to have insufficient PA levels. Many researchers regard sex-related play patterns – for example, boys' rough-and-tumble play and girls' choices of family role-playing games – to be biologically conditioned (22, 237, 238). Others theorise, however, that sex differences in physically active play – which defines most of young children's PA – are affected by social constructions (239). Findings from **Study I and II** suggest that sex differences in PA are not only biologically determined but also partly a result of environmental factors, such as season and setting (here – the preschool environment). Even though sex and age are not modifiable characteristics, it is important that PA programmes and social and physical environments (which are modifiable aspects) are designed to provide opportunities for all children to increase their PA.

Since a significant proportion of preschoolers are insufficiently physically active, and because interventions before school age provide the most cost-effective solutions (27, 28), there is a need for broad, scalable interventions to promote PA in preschoolers. It is, however, unclear from intervention studies how to successfully integrate PA during the preschool day, which type of activities are most relevant for e.g., health and FMS development, and how to target the children most in need. As the existing evidence is insufficient to shape policy, given that previous interventions have generally lacked effectiveness (210, 240), more research is needed to document effective and sustainable interventions to increase PA in preschoolers. Moreover, for future interventions to have a greater chance of success, it is essential to establish the relevant influences on PA behavior. For example, it is yet to be established in the literature whether environmental correlates of PA (such as season and setting) affect boys and girls PA to the same degree as they age (200). Understanding of the factors underlying the observed sex differences in PA among children and youth (17) could guide intervention strategies promoting PA in girls in particular. Thus, more longitudinal research is needed to investigate potential correlates of boys' and girls' PA across ages.

The early childhood years is a critical time for the development of FMS, and a certain level of competence is necessary to participate in various types of PA. Although we acknowledge the observational nature of **Study III and IV**, and the limitations it holds for drawing causal inferences, we argue that the results presented are of value for informing preschoolers' guidelines for PA. Our results suggest that preschoolers should spend time in high intensity PA to improve their FMS. Furthermore, our prospective analysis was able to determine the direction and predictive value of the relationship between PA and FMS in preschoolers, which adds valuable knowledge about the relationship between PA and FMS in this age group. The results from **Study IV** suggest that an increased focus on promotion of MVPA during the preschool years can improve the development of FMS. Surprisingly, FMS during the preschool years was not related to PA two years later. This finding, which is supported by previous research (181), supports the theory by Stodden and colleagues (166), suggesting that the relationship between PA and FMS changes over time. However, more longitudinal studies, starting at an early age, and with longer follow-up durations, are needed to investigate whether the strength and direction of the association between PA and FMS, in fact, changes during childhood and adolescence.

The participating children in PRESPAS make valuable contributions to the field of PA epidemiology in a population where large-scale studies are scarce and knowledge needed. However, younger children do not have the competence to grant legal consent to participation in research on their own behalf, and they are not able to fully understand what they are taking part in. When conducting research in preschool populations it is, therefore, particularly important to consider ethical aspects, for example by weighting benefits and possible harms of the research, and to take in to account the children's age and needs. In PRESPAS the children's positive experience were a high priority during the data collection and all test situations were performed in safe and familiar environments.

6. CONCLUSIONS

This thesis draws four main conclusions:

I. Overall, PA levels of Norwegian preschoolers are fairly similar to those seen in other studies internationally. Boys were consistently more physically active and less sedentary than girls and PA increased with age for both sexes. Our findings suggest that boys exhibit a greater increase than girls in MVPA with increasing age. Additionally, PA differed across seasons, with higher levels of MVPA during the spring and summer months than during the winter and autumn months. Finally, differences in MVPA between boys and girls, among age groups, and across seasons seem to be interrelated, indicating that many factors influence preschoolers' PA behaviours.

II. Children spent more time in MVPA during preschool hours than during time out-of-care. Similarly, children were more physically active and less sedentary on weekdays than on weekends. MVPA levels during preschool hours relative to time out-of-care were higher for boys, older children, and highly active children than for to girls, younger children, and children with lower levels of overall MVPA. Therefore, regarding MVPA, some groups of children appear to benefit more from the preschool arena than others do.

III. The PA-intensity profile associated with FMS was characterised by vigorous intensities, while weaker associations were found for MPA, LPA (both positive), and SED (negative). The strongest association was found for FMS within the locomotor domain, while the association for object control skills were somewhat weaker, but significant. No association pattern was found for balance skills.

IV. The prospective, bi-directional associations between intensity-specific PA and domain-specific FMS in young children showed that baseline PA of at least moderate intensity predicted improved FMS at follow-up. However, baseline FMS were not predictive of future PA levels.

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STUDY I

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ORIGINAL ARTICLE

WILEY

Physical activity among Norwegian preschoolers varies by sex, age, and season

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Background: Knowledge of physical activity (PA) in preschool populations is important for public health promotion. We investigated levels of PA in a large sample of Norwegian preschoolers and explored variations and development in PA by sex, age, and season.
Methods: Physical activity levels of 1154 children (mean age 4.7 years, 52% boys) were measured by accelerometry (ActiGraph GT3X+) for 14 consecutive days between autumn 2015 and summer 2016. Additionally, 330 children provided up to 3 repeated measurements of PA across seasons. A linear mixed model was applied to analyze associations and interactions of total PA (cpm), light PA (LPA), moderate PA (MPA), vigorous PA (VPA), moderate-to-vigorous PA (MVPA), sedentary time (SED), sex, age, and season.
Results: Boys and girls spent mean (standard deviation) 72 (21) and 59 (18) min/d in MVPA and had a total PA of 790 (202) and 714 (192) cpm/d, respectively. Boys had higher PA levels than girls, PA increased with age, and PA was higher during spring/summer than autumn/winter ($P < 0.001$). Boys had a greater increase in PA by age than girls ($P < 0.05$), mainly due to increased MVPA during spring/summer (p for sex × age × season=0.009).
Conclusions: Boys were consistently more active and less sedentary than girls, and PA increased with age for both sexes. Boys exhibited a greater increase than girls in PA by age, and PA differed across seasons, with higher levels of MVPA during spring/summer. Differences in MVPA between boys and girls, among age groups, and among seasons seem to be interrelated, indicating that many factors influence preschoolers' PA.

KEYWORDS
age trend, children, health behavior, objective monitoring, seasonal variation

1 | INTRODUCTION

During the preschool years, physical activity (PA) has been shown to be positively associated with psychosocial health, motor skills, cardiometabolic health indicators, and decreased adiposity.[1] Since PA levels are known to decrease over time in school-aged children and adolescents,[2] the preschool years have been highlighted as a crucial period for establishing optimal levels of PA.[3] Consequently, knowledge about levels of PA and sedentary time (SED) among young children, and identification of factors associated with PA, is important for initiating public health efforts.

The WHO recommends that children engage in ≥60 minutes of moderate-to-vigorous PA (MVPA) every day,[4] which is also the recommended level in the Nordic countries, including Norway,[5] irrespective of the child's age. For preschoolers, some countries have developed specific guidelines amounting to 180 minutes of total (non-SED) PA per day.[6,7] Most studies suggest nearly all preschoolers achieve this level of total PA[11,12]; however, many preschoolers do not meet the MVPA guideline.[15,16] To understand prevalence rates across areas with different cultural, social, and physical environments, as well as areas with different seasonal characteristics, large studies are needed from a wide range of countries. Currently, no large-scale study has determined PA objectively in Norwegian preschoolers.

It is well documented that boys are more active than girls starting from school age,[2] and evidence suggests these differences are also present in preschool-aged children.[1,3,15,17] However, sex differences in PA seem to depend on growth and development. This dependence is illustrated by differing findings between adolescent boys and girls if using biological versus chronological age,[18] and the fact that differences in PA between boys and girls do not seem to be present in 2-year-old children.[19] Furthermore, several studies have found that younger preschool children (3-4 years of age) tend to be more physically active than older preschoolers (5- to 6-year-olds),[20,21] whereas other studies indicate an opposite trend.[22,23] Thus, more research is needed to determine how PA develops with age in preschoolers and whether sex differences in PA are evident across age.

Children's PA levels are further known to vary with season, being lower in the winter, probably due to a lack of daylight and poor weather.[25] Understanding seasonal variation in PA is important for informing public health efforts, as well as for avoiding biases in surveillance studies conducted across place and time. However, the existing evidence on seasonal variation in PA is mainly drawn from between-subjects comparisons of cross-sectional data,[26] which may be subject to bias. Moreover, most studies using longitudinal designs have mainly been restricted to small samples,[26] which offer little scope for the examination of modifiers, such as sex and age. A study from the International Children's Accelerometry Database suggests that the impact of season and weather conditions on PA levels is stronger in preschool-aged children than in older children.[25] However, there are few investigations targeting seasonal variations in preschoolers; thus, further research is warranted.[25]

To the best of our knowledge, the development of PA by age, sex, and season, and how these factors moderate each other, has not yet been addressed in preschool populations. Therefore, the aims of this study were as follows: (a) to determine levels of PA by sex and age in a large cross-sectional sample of Norwegian preschoolers and (b) to investigate seasonal variations in PA by sex and age in a subsample of children having longitudinal data across seasons.

2 | METHODS

2.1 | Study design and recruitment of participants

The *Sogn og Fjordane Preschool Physical Activity Study* (PRESPAS) is a large population-based cross-sectional study conducted in the rural county of Sogn og Fjordane in western Norway. The study was conducted between September 2015 and June 2016, and recruitment of participants was performed in three steps: at the municipality level, at the preschool level, and at the child (parent) level. First, we invited 15 out of 26 municipalities in the county to participate in the study. Municipalities were strategically selected based on the population average education level, population size, geographical location, average number of children per preschool, and average number of children per preschool teacher. One municipality chose not to take part in the study. Second, we recruited preschools through the municipality preschool boards. All 74 preschools within the 14 participating municipalities that had at least six children in the appropriate age group (born in 2010, 2011 and/or 2012) were invited. The criterion for the minimum number of children was set for practical reasons and caused the exclusion of 10 preschools. Among the 74 preschools invited, three did not want to participate, and three were excluded because they did not manage to recruit children to the study. Thus, 68 preschools (92% of those invited) participated in the study. Third, we invited all children born in 2010-2012 within the 68 participating preschools to take part in the study. In total, 1925 children aged 2.7-6.5 years were invited, constituting 49% of the total population of preschoolers in Sogn og Fjordane County. In total, 1308 of the 1925 invited children participated in the study (68% of those invited; 34% of the total population of preschoolers in Sogn og Fjordane).

Additionally, we invited all children from 20 of the preschools already included in the cross-sectional sample to perform three repeated measurements of PA to capture seasonal variation. Measurements were conducted during the autumn of 2015 (September-December), winter of 2016 (January-March), and spring/summer of 2016 (April-June). Thus, 330 children (90% of participating children in these 20 preschools (n = 366)) provided longitudinal data (2 or 3 registration periods of 14 days) collected within a timeframe of 10 months (hereafter referred to as the longitudinal sample). One of the three measurements were included in the cross-sectional material (autumn 2015 for 12 preschools and winter 2016 for 8 preschools), as determined a priori to achieve a balance between seasons for these analyses.

Parents of all participating children received oral and written information about the study and provided written consent prior to testing. Children were provided an explanation of the measurements on their premises. The Norwegian Center for Research Data (NSD) approved the study (reference number: 39061).

2.2 | Procedures

Physical activity was measured using the ActiGraph GT3X+ accelerometer (ActiGraph, LLC, Pensacola, Florida, USA). We visited all preschools and explained the measurement procedure to the preschool staff and the children before the accelerometers were mounted on the children's right hip. Children were instructed to wear the accelerometer at all times for 14 consecutive days, except during water-based activities or while sleeping (at night). After the registration period, the monitors were collected at the preschool. Our criterion for a valid day was ≥480 minutes of wear time accumulated between 06:00 and 24:00 hours. Accelerometers were initialized with a sampling rate of 30 Hz and analyzed in 10-second epochs using the Kinesoft software (KineSoft version 3.3.80, Loughborough, UK). Periods of ≥20 minutes of zero counts were defined as non-wear time. We included all children providing ≥3 weekdays and ≥1 weekend day of valid data in the analysis. Outcomes were total PA (counts per min (cpm)) and intensity-specific PA, reported as sedentary time SED (≤100 cpm), light-intensity PA (LPA) (101-2295 cpm), moderate-intensity PA (2296-4011 cpm), MVPA (≥2296 cpm), and vigorous PA (VPA) (≥4012 cpm) (min/d).[27] Additionally, we reported the proportion of children who achieved the guideline amount of ≥ a mean of 60 min/d of MVPA. Because of the ongoing discussion regarding which cut points to be used in preschool populations,[28] we have provided supplemental results derived from the Pate cut points (MVPA ≥1680 cpm, SED ≤148) [29] (presented in Table S1).

Children's sex and age, parental socioeconomic status (SES: based on the highest education level *(upper secondary school, university <4 years, university ≥4 years),* and yearly income level of mother or father) were assessed using a questionnaire completed by the child's mother and/or father. Trained test leaders assessed children's body mass and height during preschool hours. Body weight was measured to the nearest 0.1 kg using an electronic scale (Seca 899, SECA GmbH, Hamburg, Germany), and height was measured to the nearest 0.1 cm with a portable stadiometer (Seca 217, SECA GmbH, Hamburg, Germany). Body mass index (BMI: kg/m^2) was calculated, and children were classified as normal weight, overweight, or obese based on the criteria suggested by Cole et al.[30]

2.3 | Statistical analysis

Children's characteristics, PA, and SED were reported as frequencies, means and standard deviations (SD). To account for the clustering of observations within preschools, all analyses for continuous outcomes were performed using a linear mixed model. For categorical outcomes, we used generalized estimating equations defining preschools as the cluster variable using an exchangeable correlation structure. In the cross-sectional analyses, we used a two-level model, including random intercepts for preschools, to analyze absolute values. In analyses of repeated measurements, we added random intercepts for children in addition to random intercepts for preschools (ie, a three-level model). The longitudinal data were analyzed using absolute values at each time point as the primary analysis. However, we also performed a sensitivity analysis using change scores between autumn (baseline) and winter, and between winter and spring/summer.[31] For age categories used in illustrations, three-year-olds are defined as <3.5 years, 4-year-olds as 3.5-4.5, 5-year-olds as 4.5-5.5, and 6-year-olds as <5.5 years. PA was the outcome in all models.

Main effects of age, sex, and season were determined by including these variables as independent variables while controlling for parental SES (income and education level), accelerometer wear time, and BMI. We thereafter tested several possible moderators for PA levels by including the interaction terms sex × age, sex × season, and age × season in the models specified above. Finally, the three-way interaction sex × age × season was included, thus allowing for the evaluation of a full factorial model. All models using absolute values were run in both the cross-sectional and the longitudinal sample. All analyses were performed in IBM SPSS v. 24 (IBM SPSS Statistics for Windows, Armonk, NY: IBMCorp., USA). A P-value <0.05 indicated statistically significant findings.

3 | RESULTS

3.1 | Description of the sample

Of the 1308 children that participated in the study, 1154 (88%) provided valid accelerometer data and were included in the analysis (Table 1). Children had a median of 13 valid days of PA registration (≤7 days: 4.4%; 8-12 days: 44.0%; >12 days: 51.6%), and on average, 698 (43) wear min per day. The majority of children had a normal weight status (82%), were born in Norway (97%), and had parents born in Norway (mothers: 89%; fathers 88%).

Attritional analyses showed that the 1154 included children were slightly older than the excluded children ($P = 0.012$) and had parents with higher incomes ($P = 0.049$) and education levels ($P = 0.003$). The included and excluded children did not differ regarding BMI ($P = 0.486$) or sex ($P = 0.954$). Participants' characteristics from the repeated measurement sample did not differ from those of the cross-sectional sample (see Table S2).

TABLE 1 Children's characteristics

	Total sample **N = 1154**	**Boys** **n = 596 (52%)**	**Girls** **n = 558 (48%)**
Age (years)	4.7 (0.9)	4.8 (0.9)	4.7 (0.9)
Ethnicity of child (n (%))			
Born in Norway	1017 (97%)	527 (97%)	490 (97%)
Mother born in Norway	927 (89%)	482 (89%)	445 (88%)
Father born in Norway	919 (88%)	483 (89%)	436 (86%)
Body mass (kg) (n = 1024)	19.4 (3.3)	19.6 (3.2)	19.2 (3.3)
Height (cm) (n = 1024)	109.1 (7.5)	109.8 (7.5)	108.3 (7.3)
BMI (kg/m2) (n = 1024)	16.2 (1.4)	16.2 (1.3)	16.3 (1.5)
Age-specific weight status (n (%))			
Normal	920 (82%)	490 (85%)	430 (79%)
Overweight	178 (16%)	79 (14%)	99 (18%)
Obese	28 (3%)	9 (2%)	19 (4%)
Parental education level[a]			
Upper secondary school	111 (10%)	57 (10%)	54 (10%)
University <4 y	458 (42%)	233 (42%)	225 (43%)
University ≥4 y	521 (48%)	270 (48%)	251 (47%)
Parental income level[a]			
<32 500 EUR	59 (6%)	30 (6%)	29 (6%)
32 500-62 000 EUR	644 (62%)	345 (64%)	299 (60%)
>62000 EUR	337 (32%)	166 (31%)	171 (34%)
Season of measurement (n (%))			
Winter	566 (49%)	283 (48%)	283 (51%)
Spring/Summer	222 (19%)	124 (21%)	98 (18%)
Autumn	366 (32%)	189 (32%)	177 (32%)

All values are mean ± SD unless stated otherwise; SD, Standard deviation; weight status defined according to Cole et al,[30]; winter: December-March; spring/summer: April-June; autumn: September-November.

[a]Parental education level and yearly income: highest level used of mother or father.

3.2 | Physical activity levels

Overall, children had a mean total PA (SD) of 754 (201) cpm and 66 (21) minutes of MVPA per day (Table 2). Boys and girls spent 10.3 (2.9)% and 8.7 (2.6)% of their daily time in MVPA, respectively. Further, boys and girls spent 48.2 (6.7)% and 50.4 (6.9)% of their daily time in SED, respectively, whereas they were in LPA 41.5 (5.3)% and 40.9 (6.0)% of their time, respectively. In total, 55% of the children accumulated a mean of ≥60 minutes of MVPA per day using the Evenson et al MVPA cut point.[27] To compare, 95% achieved this guideline amount using the Pate et al MVPA cut point[29] (Table S1). Boys and older children had a higher level of compliance with the recommendation than girls and younger children (Table 2).

3.3 | Associations between physical activity, sedentary time, sex, age, and season

Table 3 gives an overview of the results on main effect associations and interactions between PA and SED and the following factors: sex, age, and season in the longitudinal sample (see Table S3 for associated results in the cross-sectional sample). Sex differences in total PA, LPA, MPA, VPA, MVPA, and SED were similar in both samples, with boys accumulating more PA and less SED than girls (*P* < 0.01). Further, the same trend was found in both samples regarding associations between PA and age, with an increase in total PA, MPA, VPA, and MVPA by age, and a decrease in and LPA by age (*P* < 0.01). In analyses of associations between PA and season, the results were somewhat conflicting between the cross-sectional and the longitudinal sample. In the cross-sectional sample, children had more total PA, VPA, and SED, and less LPA and MPA, during the spring and summer months copmared to the winter (*P* < 0.05), and less total PA, LPA, MPA, and MVPA, and more SED, during the autumn compared to the winter (*P* < 0.05). In the longitudinal sample, children had more total PA, VPA, and MVPA, and less LPA, during the spring and summer (*P* < 0.01), and more total PA, VPA, MVPA, and SED, and less LPA, in the autumn compared to the winter (*P* < 0.05).

TABLE 2 Children's wear time, sedentary time and PA levels (mean ± SD), and compliance with PA recommendations (%)

	Total	**3-y-olds**	**4-y-olds**	**5-y-olds**	**6-y-olds**
Total sample	N = 1154	n = 112	n = 338	n = 439	n = 265
Wear time (min/d)	700 (42)	683 (48)	688 (39)	704 (40)	715 (39)
Total PA (cpm)	754 (201)	646 (140)	730 (210)	758 (182)	822 (215)
SED (min/d)	343 (54)	337 (59)	339 (52)	344 (53)	350 (54)
LPA (min/d)	288 (41)	291 (40)	286 (42)	289 (40)	286 (41)
MPA (min/d)	45 (14)	38 (11)	41 (12)	47 (13)	51 (14)
VPA (min/d)	20 (10)	13 (6)	18 (10)	20 (10)	25 (12)
MVPA (min/d)	66 (21)	52 (15)	60 (19)	68 (19)	76 (22)
≥60 min MVPA/d (%)	55	25	44	62	72
Boys	n = 596	n = 57	n = 167	n = 227	n = 145
Wear time (min/d)	704 (42)	692 (42)	692 (38)	707 (45)	715 (37)
Total PA (cpm)	790 (202)	651 (145)	774 (209)	791 (192)	858 (200)
SED (min/d)	337 (52)	338 (61)	330 (49)	340 (53)	341(52)
LPA (min/d)	291 (39)	296 (41)	292 (41)	292 (37)	289 (37)
MPA (min/d)	50 (14)	42 (12)	46 (13)	51 (13)	55 (15)
VPA (min/d)	21 (11)	13 (6)	20 (10)	22 (10)	26 (11)
MVPA (min/d)	72 (21)	55 (16)	66 (20)	73 (19)	82 (21)
≥60 min MVPA/d (%)	66	30	56	73	79
Girls	n = 558	n = 55	n = 171	n = 212	n = 120
Wear time (min/d)	696 (42)	674 (53)	685 (40)	701 (34)	714 (42)
Total PA (cpm)	714 (192)	641 (136)	686 (203)	720 (164)	777 (225)
SED (min/d)	350 (54)	336 (57)	347 (53)	350 (53)	361 (54)
LPA (min/d)	283 (43)	286 (38)	280 (44)	286 (42)	281 (46)
MPA (min/d)	41 (11)	35 (8)	37 (10)	43 (12)	45 (12)
VPA (min/d)	18 (10)	14 (7)	16 (10)	19 (9)	23 (12)
MVPA (min/d)	59 (18)	48 (13)	54 (17)	62 (17)	68 (20)
≥60 min MVPA/d (%)	43	18	29	50	61

SD: Standard deviation; SED: Sedentary time; LPA: Light physical activity; MPA: Moderate physical activity; VPA: Vigorous physical activity; MVPA: Moderate-to-vigorous physical activity.

3.4 | Moderators of physical activity

In the cross-sectional sample, there was no sex × age interaction for any of the PA variables or SED ($P = 0.151$-0.750) (Table S3). However, in the longitudinal sample, there was a significant interaction of sex × age for total PA, MPA, VPA, MVPA, and SED ($P = 0.025$-0.048) (Table 3). Total PA, MPA, VPA, and MVPA increased in both boys and girls by age, yet boys had a greater increase. Further, a different development in SED was found for boys and girls by age (positive trend in girls, negative in boys). Figure 1 illustrates both the longitudinal development and the cross-sectional differences in MVPA by age in boys and girls.

There was one significant interaction of age × season in the cross-sectional sample for MPA. The yearly difference in MPA seems to be greater during winter compared to the other seasons ($P < 0.05$). No interactions of age × season were found in the longitudinal sample. Further, no interaction of sex × season was found in the cross-sectional sample; however, there was a significant interaction of sex × season in the longitudinal sample for LPA ($P = 0.026$), MVPA ($P = 0.040$) and SED ($P = 0.045$). These results show a greater difference in MVPA between boys and girls during the winter and autumn than in the spring/summer, a smaller difference in LPA between boys and girls during winter compared to the other seasons, and greater differences in SED during the winter and spring/summer months. Boys had consistently more PA and less SED compared to girls in all seasons (Table 3). Furthermore, in the longitudinal sample we found a three-way interaction of sex × age × season for VPA ($P = 0.012$) and MVPA ($P = 0.009$), with a greater increase in VPA/MVPA by increasing age in boys than in girls during the spring and summer months than during other seasons, and opposite;a greater increase in VPA/MVPA in the youngest girls during spring and summer months than during other seasons (Table 3/Figure 2). This interaction was not

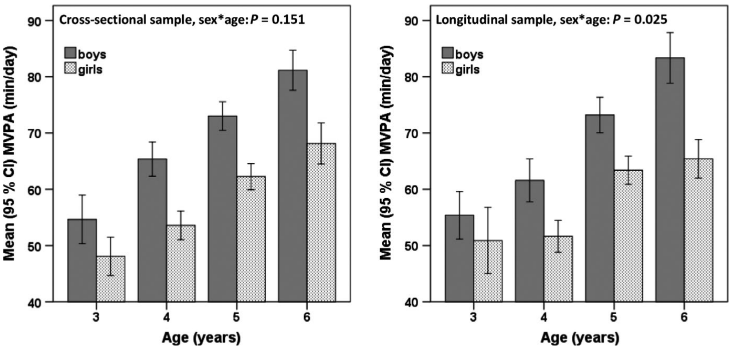

FIGURE 1 Cross-sectional distribution in moderate-to-vigorous physical activity (MVPA) by age and sex (left), and longitudinal development in MVPA by age in boys and girls (right)

present in the cross-sectional sample. Figure 2 illustrates how the change in MVPA between seasons differs between age groups among boys and girls (longitudinal sample).

4 | DISCUSSION

4.1 | Main findings

The current study examined objectively measured levels of PA and SED in a large, population-based sample of 2.7- to 6.5-year-old Norwegian preschoolers. Our results showed that boys were consistently more active and less sedentary than girls and that PA increased with age for both sexes. However, our findings suggest that boys exhibit a greater increase than girls in total PA (cpm) and MVPA with increased age. Additionally, PA differed across seasons, with higher levels of MVPA during the spring and summer months than during the winter and autumn months. Finally, differences in MVPA between boys and girls, among age groups, and among seasons seem to be interrelated, indicating that many factors influence preschoolers' PA behaviors.

4.2 | Physical activity levels

Previous studies conducted in preschool-aged children have shown low levels of PA and high levels of SED and similar low compliance with MVPA recommendations.[15,16] In the current study, boys and girls accumulated an average of 72 and 59 minutes of MVPA per day, respectively. This equals total PA levels of 790 and 714 cpm. In 2011, Bornstein et al[15] conducted a comprehensive literature review of accelerometer-derived MVPA in 6309 preschoolers (29 studies). Overall, boys and girls engaged in 54.4 and 45.4 minutes of MVPA per day, respectively. The studies included in the review using ActiGraph accelerometers reported an average of 714 cpm, with boys and girls having 783 cpm and 696 cpm, respectively.[15] Among more recent studies that address PA levels among preschoolers using the Evenson cut points, the average time spent in MVPA range from 40 to 72 minutes and 32 to 62 minutes for boys and girls, respectively.[32,33] The mean ages for the participants in the majority of these studies are, however, slightly higher than those in our sample (mean 4.5-6.0 years). Still, compared to the results by Bornstein et al[15] and to the more recent studies mentioned above, our preschoolers seem to have PA levels rather similar to other studies internationally.

Until recently, several countries have been recommending that preschoolers participate in 180 minutes of total (non-SED) PA per day, regardless of intensity. However, most studies suggest that nearly all preschoolers achieve this amount of PA.[11,12] In the current study, we found that all children, regardless of the two cut points for SED tested,[27,29] met the recommendation of three hours of daily engagement in PA (results not shown). There is, however, growing evidence that MVPA is associated with greater health benefits than PA that is less intense.[36] Therefore, we find the level of compliance with the MVPA recommendation more relevant, although this level is highly affected by the choice of cut points to define MVPA.[37] Because of the ongoing debate on the accelerometer cut points that accurately reflect the various intensities of PA among preschool-aged children, we chose to analyze our data with two different sets of cut points, both widely used in preschool populations.[28] Depending on the cut points applied (Evenson or Pate), we found that 55%-95% of the children achieved the guideline amount of 60 minutes MVPA per day (Table 2 and Table S1). The variability in PA levels resulting from application of different cut points pose significant challenges to our understanding of PA levels of young children and whether PA interventions are needed. It is also important to note that cut points validated in a specific age group might not be valid for other age groups due to different PA patterns, and it has therefore been argued that

TABLE 3 Associations and interactions among physical activity, sedentary time, sex, age, and season using repeated measurements

	Longitudinal sample (n = 330)					
	β (95% CI)					
	Total PA	**SED**	**LPA**	**MPA**	**VPA**	**MVPA**
Main effects						
Sex (girls vs boys)	−62.3 (−95.0, −29.6)**	19.9 (10.7, 27.3)**	−9.2 (−15.6, −2.9)**	−7.8 (−10.1, −5.4)**	−2.2 (−3.8, −0.6)**	−9.8 (−13.5, −6.2)**
Age (change per year)	58.2 (38.6, 77.8)**	−1.1 (−6.1, 3.8)	−7.5 (−11.4, −3.7)**	4.8 (3.4, 6.2)**	3.7 (2.8, 4.7)**	8.5 (6.4, 10.7)**
Season (ref. winter)						
Spring/summer	163.7 (139.4, 188.0)**	1.2 (−5.0, 7.5)	−11.2 (−16.4, −5.9)**	−0.7 (−2.3, 0.9)	10.6 (9.4, 11.7)**	10.0 (7.7, 12.2)**
Autumn	67.1 (43.8, 90.5)**	7.4 (1.4, 13.4)	−14.5 (−19.6, −9.5)**	−0.1 (−1.5, 1.5)	6.9 (5.8, 8.0)**	6.8 (4.7, 9.0)**
Two-way interactions						
Sex × age	*P* = 0.044	*P* = 0.043	*P* = 0.161	*P* = 0.048	*P* = 0.030	*P* = 0.025
Age (change per year)						
Boys	75.6 (45.5, 105.6)	−4.9 (−11.6, 1.9)	−5.8 (−10.8, −0.8)	6.1 (4.0, 8.2)	4.6 (3.2, 6.1)	10.7 (7.4, 14.1)
Girls	31.4 (5.8, 57.0)	6.2 (−1.6, 14.0)	−11.2 (−17.5, −4.9)	2.7 (0.8, 4.6)	2.4 (1.2, 3.6)	5.2 (2.5, 7.9)
Age × season	*P* = 0.876	*P* = 0.391	*P* = 0.345	*P* = 0.106	*P* = 0.165	*P* = 0.833
Age (change per year)						
Winter	61.9 (40.5, 83.3)	−5.9 (−13.9, 2.2)	−4.0 (−10.8, 2.7)	6.5 (4.5, 8.5)	3.4 (2.5, 4.2)	9.8 (7.3, 12.4)
Spring/summer	61.1 (27.1, 95.1)	2.4 (−3.3, 8.1)	−10.4 (−14.6, −6.3)	3.8 (2.0, 5.6)	4.4 (2.8, 6.0)	8.2 (5.0, 11.4)
Autumn	58.6 (34.7, 82.6)	0.1 (−5.6, 5.8)	−8.2 (−12.5, −4.0)	4.3 (2.6, 5.9)	4.0 (2.8, 5.2)	8.2 (5.5, 10.9)
Sex × season	*P* = 0.094	*P* = 0.045	*P* = 0.026	*P* = 0.137	*P* = 0.088	*P* = 0.040
Gender difference (ref. boys)						
Winter	−62.7 (−97.4, −27.9)	12.0 (−1.1, 25.2)	−1.9 (−12.9, 9.1)	−7.5 (−10.8, −4.3)	−2.7 (−4.1, −1.3)	−10.3 (−14.4, −6.1)
Spring/summer	−54.6 (−110.2, 1.1)	20.2 (10.9, 29.5)	−11.1 (−17.8, −4.4)	−7.3 (−10.2, −4.4)	−1.5 (−4.2, 1.1)	−8.8 (−13.9, −3.6)
Autumn	−75.8 (−113.8, −37.8)	25.8 (16.7, 34.8)	−14.5 (−21.1, −7.8)	−8.6 (−11.2, −6.0)	−2.6 (−4.6, −0.7)	−11.1 (−15.3, −6.9)
Three-way-interactions						
Sex × age × season	*P* = 0.066	*P* = 0.429	*P* = 0.251	*P* = 0.085	*P* = 0.012	*P* = 0.009
Age (change per year)						
Boys						
Winter	65.3 (34.3, 96.3)	−8.9 (−19.4, 1.7)	−1.6 (−10.0, 6.8)	7.1 (4.1, 10.1)	3.3 (2.1, 4.6)	10.3 (6.5, 14.2)
Spring/summer	92.5 (40.1, 144.8)	−1.8 (−9.7, 6.0)	−9.6 (−15.3, −4.0)	5.7 (3.2, 8.3)	6.2 (3.7, 8.7)	11.9 (7.2, 16.7)
Autumn	63.5 (28.1, 98.9)	−1.1 (−8.7, 6.6)	−7.6 (−13.1, −2.1)	4.5 (2.0, 7.0)	4.2 (2.3, 6.1)	8.6 (4.5, 12.7)

(Continues)

TABLE 3 (Continued)

	Longitudinal sample (n = 330)					
	β (95% CI)					
	Total PA	SED	LPA	MPA	VPA	MVPA
Girls						
Winter	46.9 (16.3, 77.4)	3.4 (−9.7, 16.5)	−11.7 (−23.1, −0.2)	4.9 (2.2, 7.7)	3.5 (2.3, 4.8)	8.4 (5.0, 11.9)
Spring/summer	9.7 (−35.0, 54.5)	10.2 (1.9, 18.4)	−12.8 (−19.3, −6.2)	0.7 (−1.7, 3.1)	1.7 (−0.3, 3.6)	2.2 (−1.7, 6.2)
Autumn	42.6 (8.5, 76.7)	2.4 (−6.7, 11.5)	−8.4 (−15.3, −1.5)	3.2 (0.9, 5.5)	2.9 (1.3, 4.5)	6.1 (2.6, 9.7)

The β coefficient represents the difference in min spent sedentary (SED), in light physical activity (LPA), moderate physical activity (MPA), vigorous physical activity (VPA), and in moderate-to-vigorous physical activity (MVPA) and the difference in total physical activity (total PA) (cpm) compared to the reference category or as change per year. Final results from a three-level random intercept model adjusted for sex, age, BMI, parental education (highest level of mother or father), parental income level (highest yearly income of mother or father), season (winter: January-March; spring/summer: April-June; autumn: September-December), and accelerometer wear time (min per day), with "preschool" and "child" as cluster effects.

$^{*}P < 0.05$, $^{**}P < 0.01$.

these criteria should be age-specific.[28] However, we did not include age-specific cut points in the current study. Our findings of increased PA levels by age, with only 25% of the 3-year-olds achieving the MVPA guideline compared to 72% of the 6-year-olds (Table 2), are thus somewhat challenging. This finding suggests that the MVPA guideline and/or the MVPA cut point applied herein is not developmentally appropriate in the population of preschoolers.

4.3 | Associations and interactions between physical activity and sex, age, and season

Reviews that have addressed correlates of preschool children's PA[17,38] reports "sex" as the most frequent individual correlate. Our results support this evidence, showing consistently higher PA (and less SED) among boys compared to girls. Despite conflicting findings regarding the association between PA and age in the preschool population, our results are consistent with the most recent updates concluding that PA in the preschool population increases by age.[17] In the current study, children had a mean increase of 58.2 (95% CI: 38.6, 77.8) cpm and 8.5 (95% CI: 6.4, 10.7) min/d in MVPA per year (Table 3). However, the increase by age seems to depend on sex, as we found a more pronounced increase in total PA, MPA, VPA, and MVPA in boys than in girls (the sex × age interaction was statistically significant in the longitudinal sample, although not in the cross-sectional sample). Similar differing trends were found in a longitudinal study of 498 preschoolers from Switzerland, although not statistically significant.[23] There are, however, few longitudinal studies investigating development in PA with age in preschoolers, and results among these are conflicting.[20,22,23] For example, a study of 208 preschool-aged children in New Zealand found a decline in MVPA for both boys and girls from ages three to four years.[20] These conflicting findings could be explained by differences in the preschool environment for play opportunities, methodological discrepancies in processing of PA data, or cultural differences, for example related to school preparation among the older preschoolers, or the amount of outdoor time, which is associated with higher levels of total PA and MVPA.[39]

In general, children's objectively measured MVPA tend to be lower in the winter relative to the rest of the year.[26] Previous research suggests that preschoolers are more affected by season and weather conditions than older children and adolescents.[25] However, few studies have examined the relationships between season and PA among preschool-aged children, and where these associations have been studied, the results are inconclusive.[25] Additionally, previous research has suggested that the seasonal patterns in children's PA are not necessarily present in all geographical areas, probably due to cultural and environmental differences.[40] Our analyses show, however, that the PA levels of Norwegian preschoolers are

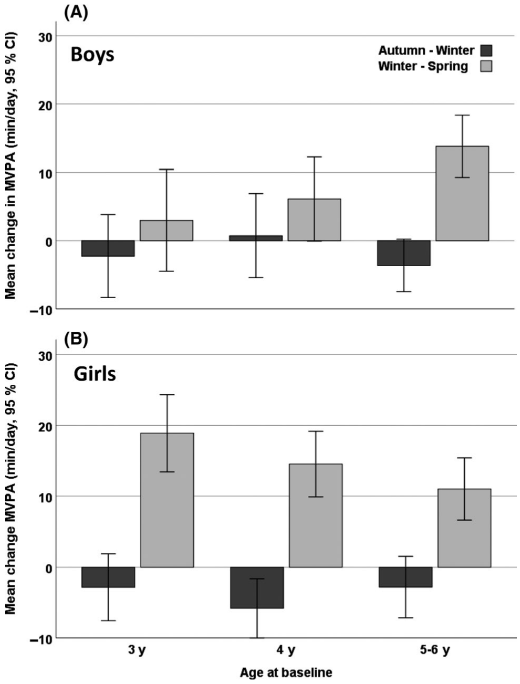

FIGURE 2 Change in moderate-to-vigorous physical activity (MVPA) between autumn (September 2015) and winter (January 2016), and between winter and spring (May 2016), by baseline age (years) in boys and girls (longitudinal sample). The change in MVPA (min/d) between autumn (baseline) and winter were −2.5 (14.7), −2.6 (17.8), and −3.2 (16.9) for children aged 3, 4, and 5-6 at baseline, respectively. For the development between winter and autumn, the change in MVPA (min/d) was 11.2 (18.0), 10.5 (19.9), and 12.5 (17.8) for children aged 3, 4, and 5-6 at baseline, respectively

highly associated with season, with more total PA, VPA, and MVPA, and less LPA and SED during the spring and summer compared to the winter and autumn. This might be an expected finding, which is also in line with findings in older Norwegian children and adolescents,[41,42] given the great variation in weather conditions and daylight between seasons in Norway.

In our sample, the PA pattern across seasons appeared to differ by age and sex (Figure 2). While no two-way-interaction was found between age and season for any of the PA variables or SED in the longitudinal sample, we did find a two-way interaction between sex and season, with greater gender differences in MVPA during the winter and autumn than during spring/summer. Furthermore, boys had a greater yearly increase than girls in VPA and MVPA during the spring and summer months (VPA: 6.2 vs 1.7 min/d; MVPA: 11.9 vs 2.2 min/d), illustrated by the significant three-way interactions of sex, age, and season (Table 3). For girls, the trend was opposite, with the youngest children having the greatest increase in VPA/MVPA from winter to spring/summer (Figure 2). These results suggest boys and girls across age have different seasonal patterns of moderate-to-high intensity PA. It seems that the oldest boys and the youngest girls increases their PA levels more during periods when it is easier to be highly physically active (spring/summer). This finding is difficult to explain, but we speculate that the spring and summer months, which are periods characterized by good weather and much daylight, provides more opportunities for outdoor play who older boys to a greater extent than girls seem to exploit. At the same time, we speculate that the youngest girls (who are the least active) might be most restricted with regard to physically active play during winter, especially when playing outdoors, and thus have the greatest potential to change their PA levels to the spring/summer.

4.4 | Perspectives

Many researchers regard different sex-related play patterns—for example, boys' rough-and-tumble play and girls' playing family role-playing games—as biologically conditioned.[44,45] Others theorize, however, that sex differences in physically active play are also affected by social constructions.[46] Findings from the current study suggest that sex differences in PA are not only biologically determined but also partly a result of environmental impacts, such as season and social expectations to boys and girls. Even though sex and age are not modifiable characteristics, it is important that PA programs and social and physical environments (which are modifiable aspects) are designed to provide opportunities for all children to increase their PA. It is, however, uncertain whether the interactions found in this study are present both during preschool hours and at home, and further research is needed to investigate the preschool's role for PA.

In the current study, there were some inconsistent results between the cross-sectional and longitudinal analyses. Even though the children in both samples accumulated most PA during the spring and summer months, seasonal variation in PA was different during the autumn and winter months in the two data sets. Further, there was only one significant interaction in the cross-sectional sample (age × season for MPA), in contrast to significant interactions for both sex × age, sex × season and sex × age × season in the longitudinal sample (Table 3). These contradictory findings highlight the importance of repeated measures and within-subjects analyses when investigating age trends and seasonal variation in PA, which probably provides more reliable results than using single measurements. Importantly, the longitudinal analyses in the present study are based on data from two to three 14-day accelerometer measurements, which lay a strong foundation for analyzing trends over time.

4.5 | Strengths and limitations

This is the first large-scale population-based study to describe objectively measured PA levels of Norwegian preschoolers. In addition to the large study sample, the wide age range, the high response rate, the good compliance with the accelerometer protocol, and the long monitoring period are major strengths of the present study. Moreover, we assessed PA longitudinally over three seasons in a subsample of children, allowing for analyses of seasonal variation and of the development of PA with age within subjects, although over a short time span. However, as previously discussed, accelerometers are not without limitations. In addition to challenges related to cut points and other methodological considerations, the accelerometer do not correctly capture certain activities, such as cycling, swimming, and other non-load bearing activities, which is a limitation to our study. In addition, accelerometer data do not provide information about the type of PA or the context in which the PA is conducted.

The idea behind the use of multilevel techniques to analyze longitudinal data is that the regression coefficients are allowed to differ between subjects (as the observations within one subject over time are correlated).[31] However, because a longitudinal mixed model combines "between-subject" and "within-subject" relationships, the approach could be problematic if the variation in absolute values between subjects exceeds the changes over time within subjects.[31] The consequence would be that the cross-sectional component may overrule the longitudinal component in the analysis, and such underestimate the longitudinal associations. Considering this issue, we analyzed the data using both absolute values and change scores over time,[31] and found our results were robust across these approaches.

Regarding seasonal variation in PA, this study is limited by the lack of weather and temperature data, which may lead to an attenuation of associations to PA if the weather during the registration period were atypical for the season. Further, participants were recruited through the preschools they attended, which leads to an exclusion of children who did not attend preschool at the time. However, in Norway, 97% of children aged 3-5 years attend preschool[47]; therefore, only ≈3% of the population of interest were excluded based on preschool attendance. The average parental socioeconomic status (SES) among the included children was higher than among the excluded children, and slightly higher than the average level for this area.[48] Further, almost all of the participating children were born in Norway. This means that the current study, despite the large sample and high response rate, might be exposed to selection bias. The results should therefore be generalized to populations of ethnic minorities or populations with lower SES with caution.

5 | CONCLUSIONS

This study confirms that boys are more physically active and less sedentary than girls and that levels of PA are highly positively associated with age in preschoolers. Further, we found that the development MVPA is likely to be moderated by sex, with greater increases by age in boys than in girls. In addition, we found that seasonal variation in PA is evident among Norwegian preschoolers, with higher PA levels during the spring and summer months than the rest of the year. Finally, differences in MVPA between boys and girls, among age groups, and among seasons seem to be interrelated, indicating that many factors influence preschoolers' PA behaviors. It is important that PA programs and social and physical home and preschool environments are designed to provide opportunities for all children to increase their MVPA during all seasons.

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CONFLICT OF INTEREST

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

EAA designed and obtained funding for the study. EAA, SAA, and AKON were involved in the development of the research questions. AKON, EY, KJ, and EAA performed the data collection. AKON and EAA analyzed the data. AKON drafted the manuscript. All authors contributed to the interpretation of data and were involved in critical revisions of the manuscript. All authors read and approved the final version.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Parents of all participating children received oral and written information about the study and provided written consent prior to testing. The Norwegian Centre for Research Data (NSD) approved the study (reference number 39061).

AVAILABILITY OF DATA AND MATERIAL

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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Supplementary Table 1. Children's wear time, sedentary time and PA levels (mean ± SD), and compliance with PA recommendations (%) using the Pate et al., cut points to define PA-intensities.

		Total	**3 yr olds**	**4 yr olds**	**5 yr olds**	**6 yr olds**
Total		*n = 1154*	*n = 112*	*n = 338*	*n = 439*	*n = 265*
	Wear time (min/day)	700 (42)	683 (48)	688 (39)	704 (40)	715 (39)
	CPM (day)	754 (201)	646 (140)	730 (210)	758 (182)	822 (215)
	SED (min/day)	364 (54)	358 (60)	360 (51)	365 (54)	371 (53)
	LPA (min/day)	229 (33)	233 (32)	229 (34)	230 (32)	226 (32)
	MPA (min/day)	71 (19)	64 (18)	66 (17)	73 (19)	76 (20)
	VPA (min/day)	31 (13)	22 (8)	27 (12)	32 (12)	37 (15)
	MVPA (min/day)	102 (28)	85 (23)	94 (26)	105 (26)	113 (29)
	≥ 60 min MVPA/day (%)	95 %	89 %	92 %	97 %	98 %
Boys		*n = 596*	*n = 57*	*n = 167*	*n = 227*	*n = 145*
	Wear time (min/day)	704 (42)	692 (42)	692 (38)	707 (45)	715 (37)
	CPM (day)	790 (202)	651 (145)	774 (209)	791 (192)	858 (200)
	SED (min/day)	359 (53)	356 (61)	351 (49)	362 (53)	363 (52)
	LPA (min/day)	231 (31)	236 (35)	233 (34)	231 (29)	227 (29)
	MPA (min/day)	76 (19)	69 (21)	72 (17)	78 (19)	81 (20)
	VPA (min/day)	33 (14)	22 (8)	30 (13)	34 (12)	40 (14)
	MVPA (min/day)	109 (28)	91 (25)	102 (26)	112 (26)	121 (29)
	≥ 60 min MVPA/day (%)	97 %	93 %	96 %	98 %	99 %
Girls		*n = 558*	*n = 55*	*n = 171*	*n = 212*	*n = 120*
	Wear time (min/day)	696 (42)	674 (53)	685 (40)	701 (34)	714 (42)
	CPM (day)	714 (192)	641 (136)	686 (203)	720 (164)	777 (225)
	SED (min/day)	371 (54)	361 (59)	269 (52)	369 (54)	381 (53)
	LPA (min/day)	227 (35)	230 (30)	226 (35)	229 (35)	224 (36)
	MPA (min/day)	65 (17)	58 (14)	61 (15)	69 (18)	70 (18)
	VPA (min/day)	28 (12)	21 (8)	25 (11)	29 (11)	34 (15)
	MVPA (min/day)	93 (25)	79 (18)	85 (22)	98 (24)	103 (26)
	≥ 60 min MVPA/day (%)	93 %	86 %	88 %	96 %	96 %

SD: Standard deviation; MVPA: Moderate to vigorous physical activity; LVPA: Light to vigorous physical activity. Cut-points mean values SED, PA intensities and compliance level with PA recommendations: Pate et al., 2006.

Supplementary Table 2. Children's characteristics, longitudinal sample (n=330).

	Total sample n = 330	**Boys n = 168**	**Girls n = 162**
Age[a] (years)	4.4 (0.9)	4.4 (0.9)	4.4 (0.8)
Ethnicity of child (%)			
Born in Norway	98 %	99 %	98 %
Mother born in Norway	88 %	94 %	89 %
Father born in Norway	88 %	92 %	90 %
Body mass (kg) [a]	18 (3)	19 (3)	18 (3)
Height (cm)[a]	106 (8)	106 (8)	106 (7)
BMI (kg/m^2)[a]	16 (1)	16 (1)	16 (1)
Age-specific weight status (%)[a]			
Normal	82 %	83 %	82 %
Overweight	16 %	16 %	16 %
Obese	2 %	1 %	2 %
Parental education level (%)[b]			
Upper secondary school	27 %	26 %	28 %
University < 4 years	33 %	36 %	31 %
University ≥ 4 years	40 %	38 %	41 %
Parental income level (%)[b]			
< 32500 EUR	6 %	5 %	6 %
32500-62000 EUR	63 %	63 %	63 %
> 62000 EUR	31 %	32 %	31 %
Season of measurement (n (%))			
Winter	308 (34 %)	158 (34 %)	150 (34 %)
Spring/Summer	290 (32 %)	149 (32 %)	141 (32 %)
Autumn	305 (34 %)	153 (33 %)	152 (34 %)
N valid PA measurement periods (n (%))			
2/3	87 (19 %)	44 (19 %)	43 (19 %)
3/3	243 (81 %)	124 (81 %)	119 (81 %)
Physical activity			
Wear time (min/day)	693 (43)	696 (44)	691 (41)
Total PA (cpm)	754 (202)	785 (211)	722 (186)
SED (min/day)	336 (51)	328 (49)	344 (51)
LPA (min/day)	289 (38)	293 (34)	284 (40)
MPA (min/day)	45 (14)	50 (15)	41 (11)
VPA (min/day)	20 (10)	21 (11)	18 (9)
MVPA (min/day)	65 (22)	71 (24)	59 (18)
≥ 60 min MVPA/day (%)	57 %	66 %	47 %
≥ 180 min LVPA/day (%)	100 %	100 %	100 %

All values are mean ± SD unless stated otherwise; SD: Standard deviation; weight status defined according to Cole et al., 2000; winter: December-March; spring/summer: April-June; autumn: September-November. [a] Levels at baseline reported (autumn 2015); [b] Parental education level and yearly income: highest level used of mother or father.

Supplementary Table 3. Associations and interactions among physical activity, sedentary time, sex, age, and season using cross-sectional data (N=1154).

Cross-sectional sample (N = 1154)

			β (95 % CI)					
			Total PA	**SED**	**LPA**	**MPA**	**VPA**	**MVPA**
Main effects								
Sex (girls vs. boys)			-57.9 (-79.9, -35.8)**	14.5 (8.8, 20.1)**	-4.8 (-9.3, -0.2)*	-7.7 (-9.1, -6.2)**	-2.1 (-3.2, -1.0)**	-9.7 (-11.9, -7.5)*
Age (change per year)			50.2 (36.6, 63.8)**	-2.6 (-6.1, 0.9)	-4.7 (-7.5, -1.9)**	4.5 (3.6, 5.4)**	3.0 (2.4, 3.7)**	7.6 (6.2, 9.0)*
Season (ref. winter)		*Spring/summer*	60.8 (13.0, 108.7)*	11.8 (0.6, 22.9)*	-15.5 (-25.9, -5.2)**	-3.1 (-5.7, -0.6)*	6.0 (3.2, 8.8)**	3.5 (-0.6, 7.5)
		Autumn	-102.4 (-143.9, -60.9)**	27.9 (18.3, 37.5)**	-23.2 (-32.3, -14.2)**	-4.0 (-6.2, -1.8)**	-1.1 (-3.5, 1.4)	-5.1 (-8.6, -1.7)*
Two-way interactions								
Sex*age			**p=0.522**	**p=0.402**	**p=0.750**	**p=0.168**	**p=0.354**	**p=0.151**
Age (change per year)		*Boys*	57.5 (37.5, 77.5)	-3.2 (-8.2, 1.7)	-5.3 (-9.2, -1.5)	5.1 (3.7, 6.5)	3.5 (2.5, 4.4)	8.6 (6.7, 10.8)
		Girls	43.7 (25.0, 62.5)	-1.1 (-6.1, 3.9)	-5.1 (-9.3, -0.9)	3.8 (2.7, 5.0)	2.7 (1.8, 3.7)	6.6 (4.8, 8.5)
Age*season			**p=0.251**	**p=0.302**	**p=0.339**	**p=0.040**	**p=0.113**	**p=0.075**
Age (change per year)		*Winter*	59.7 (40.2, 79.1)	-4.9 (-10.4, 0.5)	-3.5 (-8.1, 1.0)	5.7 (4.3, 7.1)	3.0 (2.1, 3.9)	9.0 (7.0, 11.0)
		Spring/summer	53.0 (13.1, 92.9)	1.8 (-5.4, 9.0)	-9.3 (-14.7, -3.8)	3.2 (1.2, 5.2)	4.1 (2.1, 6.1)	7.4 (3.8, 10.9)
		Autumn	33.0 (13.7, 52.4)	-1.4 (-6.8, 4.0)	-4.0 (-8.1, 0.1)	3.5 (2.0, 4.9)	2.1 (1.1, 3.1)	5.5 (3.2, 7.7)
Sex*season			**p=0.214**	**p=0.188**	**p=0.254**	**p=0.440**	**p=0.236**	**p=0.350**
Gender difference (ref. boys)		*Winter*	-40.6 (-71.8, -9.4)	9.7 (0.9, 18.5)	-1.2 (-8.5, 6.1)	-7.2 (-9.4, -4.9)	-1.3 (-2.8, 0.2)	-8.4 (-11.6, -5.3)
		Spring/summer	-70.6 (-137.9, -3.3)	17.8 (5.7, 29.9)	-5.6 (-14.8, 3.6)	-9.7 (-13.1, -6.3)	-2.7 (-6.1, 0.7)	-12.3 (-18.3, -6.4)
		Autumn	-80.6 (-111.6, -49.7)	20.0 (11.3, 28.6)	-9.3 (-15.8, -2.7)	-7.5 (-9.8, -5.2)	-3.3 (-4.9, -1.8)	-10.7 (-14.3, -7.1)
Three-way-interactions								
Sex*age*season			**p=0.296**	**p=0.126**	**p=0.086**	**p=0.710**	**p=0.810**	**p=0.674**
Age (change per year)	Boys	*Winter*	81.7 (55.1, 108.2)	-7.7 (-15.0, -0.5)	-2.6 (-8.4, 3.1)	6.5 (4.4, 8.6)	3.9 (2.6, 5.2)	11.0 (8.2, 13.8)
		Spring/summer	33.5 (-21.5, 88.5)	7.6 (-3.1, 18.4)	-14.1 (-22.1, -6.1)	2.6 (-0.4, 5.7)	3.9 (1.2, 6.5)	6.5 (1.5, 11.5)
		Autumn	42.3 (9.2, 75.3)	-3.3 (-11.7, 5.1)	-3.9 (-10.3, 2.5)	4.9 (2.6, 7.2)	2.6 (0.9, 4.3)	7.3 (3.6, 11.0)
	Girls	*Winter*	42.9 (14.4, 71.5)	-0.1 (-8.5, 8.3)	-6.5 (-13.7, 0.7)	4.6 (2.7, 6.4)	2.6 (1.2, 3.9)	7.4 (4.7, 10.1)
		Spring/summer	73.8 (12.9, 134.7)	-3.1 (-12.2, 6.0)	-5.1 (-12.3, 2.1)	3.9 (1.3, 6.4)	4.5 (1.3, 7.8)	8.3 (3.2, 13.4)
		Autumn	25.4 (3.6, 47.1)	-0.9 (-8.0, 6.2)	-3.1 (-8.5, 2.2)	2.6 (0.9, 4.3)	1.6 (0.6, 2.7)	4.2 (1.6, 6.8)

The β coefficient represents the difference in min spent sedentary (SED), in light physical activity (LPA), moderate physical activity (MPA), vigorous physical activity (VPA), and in moderate-to-vigorous physical activity (MVPA) and the difference in total physical activity (total PA) (cpm) compared to the reference category or as change per year. Final results from a two-level random intercept model adjusted for sex, age, BMI, parental education (highest level of mother or father), parental income level (highest yearly income of mother or father), season (winter: January-March; spring/summer: April-June; autumn: September-December), and accelerometer wear time (min per day), with "preschool" as a cluster effect. *p < 0.05; ** p < 0.01.

STUDY II

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Boys, older children, and highly active children benefit most from the preschool arena regarding moderate-to-vigorous physical activity: A cross-sectional study of Norwegian preschoolers

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ABSTRACT

The preschool environment exerts an important influence on children's behaviour, including physical activity (PA). However, information is lacking regarding where and when most of children's PA is undertaken. This study aimed to describe PA and sedentary time (SED) during preschool hours and time out-of-care, and on weekdays and weekend days, and to investigate differences in PA patterns according to sex, age, and MVPA levels. From September 2015 to June 2016, we measured PA levels of 1109 children (age range, 2.7–6.5 years; mean age 4.7 years; boys, 52%) using ActiGraph GT3X+ accelerometers for up to 14 consecutive days. We applied a linear mixed model to analyse associations and interactions between total PA (counts per minute [cpm]), light PA (LPA), moderate-to-vigorous PA (MVPA), SED, sex, age, and overall MVPA regardless of setting, during preschool hours versus time out-of-care, and on weekdays versus weekend days. Children undertook more PA and less SED on weekdays compared to weekend days ($p < 0.01$). For boys, MVPA levels were higher during preschool hours than during time out-of-care ($p < 0.05$). Differences in total PA and MVPA between preschool hours versus time out-of-care, and between weekdays and weekend days, were greater in boys, older children, and highly active children than in girls, younger children, and children with lower overall MVPA levels ($p < 0.01$). The preschool arena is important for children's PA. Concerning MVPA, this study showed that boys, older children, and highly active children benefit more from this environment compared to girls, younger preschoolers, and children with lower MVPA levels.

1. Introduction

Physical activity (PA) during the preschool years has been favourably associated with children's health and development, in terms of adiposity, cardiometabolic indicators, psychosocial health, and development of fundamental motor skills (Timmons et al., 2012). Moreover, especially moderate-to-vigorous PA (MVPA) has been associated with reduced metabolic risk in children (Janssen and Leblanc, 2010; Poitras et al., 2016; Ekelund et al., 2012; Andersen et al., 2006), and is important in preventing childhood obesity (Lambourne and Donnelly, 2011). However, low levels of MVPA have been reported in preschool-aged children internationally (Bornstein et al., 2011; Reilly, 2010; Hnatiuk et al., 2014).

Although parents provide most of young children's care, children under the age of 6 also spend large amounts of time in preschools. In Norway, 97% children aged 3–5 years attend preschools (Statistics Norway, 2017) (hereafter defined as preschoolers), which is an even higher percentage than the European mean attendance rate (90%) (European Commission, 2009). Additionally, Norwegian preschoolers spend an average of 33 h per week in preschool (The Norwegian

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Abbreviations: PA, physical activity; TPA, total physical activity; SED, Sedentary behaviour; LPA, light physical activity; MVPA, moderate-to-vigorous physical activity; Min, minutes; cpm, counts per minute; SD, standard deviation; SES, Socioeconomic status; CI, confidence interval; ICC, intraclass correlation

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Directorate for Education and Training, 2017). Consequently, this environment potentially exerts a significant influence on children's behaviour, including PA.

Objective monitoring of PA in preschoolers has increased in recent years. However, most previous studies have only reported PA during preschool hours or total PA regardless of setting, and have not considered the potential individual differential effect of time and place on children's PA. Knowledge of where and when preschoolers are physically active is essential to initiate interventions aimed to increase PA in young children, and to make specific recommendations on how preschoolers should attain guideline amounts of PA (in Norway: 60 min MVPA/day regardless of the child's age (Tetens, 2012). Nevertheless, some studies have shown that PA in preschoolers differs over the course of the day and the week (Hesketh et al., 2015; Van Cauwenberghe et al., 2012; O'Dwyer et al., 2014; Hesketh et al., 2014; Moller et al., 2017; Berglind and Tynelius, 2017; O'Neill et al., 2016). However, these studies are limited due to small sample sizes (size range, n = 188–341) (Hesketh et al., 2015; O'Dwyer et al., 2014; Moller et al., 2017; O'Neill et al., 2016) and, more importantly, results are conflicting regarding where and when children are most active. Some studies have reported that children are least active during preschool hours (Van Cauwenberghe et al., 2012; O'Dwyer et al., 2014; O'Neill et al., 2016), while other studies have found that children undertook more total PA and MVPA during preschool hours compared to time out-of-care (Hesketh et al., 2015; Moller et al., 2017; Berglind and Tynelius, 2017).

A recent review by Tonge et al. concluded that differences in PA exist between boys and girls and across age groups within the preschool population (Tonge et al., 2016), in favour of boys and older children. However, there is limited evidence on whether the observed sex- and age differences in PA are present to a similar degree across settings, or whether such differences depend on overall PA levels.

This study aimed to describe the distribution of PA and sedentary time (SED), in particular MVPA, during preschool hours vs. time out-of-care, and on weekdays vs. weekend days, in a large sample of Norwegian preschoolers, and to investigate differences in PA patterns across sex, age, and overall MVPA levels.

2. Methods

2.1. Study design and recruitment of participants

The Sogn og Fjordane Preschool Physical Activity Study was a population-based cross-sectional study conducted in the rural county of Sogn og Fjordane in western Norway, between September 2015 and June 2016. Out of 26 municipalities in the county, 15 were invited to participate. Municipalities were strategically selected based on the population average parental education level, population size, and geographical location, average number of children per preschool, and average number of children per preschool teacher. One municipality chose not to take part in the study. In total, 68 of 74 invited preschools participated in the study. All 1925 children born in 2010–2012 within the participating preschools were invited, of whom parents received oral and written information about the study. Parents of 1308 children provided written consent prior to testing (response rate; 68%). We explained procedures to the participating children according to their level of understanding. The Norwegian Centre for Research Data (NSD) approved the study (reference number: 39061).

2.2. Procedures

PA was measured using the ActiGraph GT3X+ accelerometer (ActiGraph, LLC, Pensacola, Florida, USA). Accelerometers were mounted on a participating child's right hip, and children were instructed to wear the monitor at all times for 14 consecutive days, except during water-based activities and while sleeping (at night). Accelerometers were initialized with a sampling rate of 30 Hz and analysed in 10-s epochs using KineSoft software (KineSoft version 3.3.80, Loughborough, UK). Periods of ≥20 min of zero counts were defined as non-wear time (Esliger et al., 2005). “Preschool hours” were based on average delivery/pick-up time for the current sample (time-stamped data), defined as between 08:30 am and 15:29 pm on weekdays (SD ± 0:30 h for both time points). All leisure time, including “morning” (06:00–08:29 h) and “afternoon” (15:30–23:59 h) on weekdays, was defined as “time out-of-care”. Our criterion for a valid day was ≥480 min of wear time accumulated between 06:00 and 24:00 h (both weekdays and weekend days). All participants included in the analysis for the present study had to have ≥30 min wear time in the “morning”, ≥270 min wear time during “preschool hours”, and ≥ 180 min in the “afternoon” on weekdays. We included all children who provided ≥3 weekdays and ≥ 1 weekend day of valid data in the analysis. Outcomes were total PA (TPA) (counts per min [cpm]) and intensity-specific PA, reported as SED (≤100 cpm), light-intensity PA (LPA) (101–2295 cpm), and MVPA (min/day) (≥2296 cpm) (Evenson et al., 2008).

Children's sex, age, and parental socioeconomic status (SES, based on the highest education level and the highest yearly income of mother or father) were assessed using a questionnaire that had been completed by the child's mother and/or father. We assessed children's body weight and height during preschool hours. Body weight was measured to the nearest 0.1 kg using an electronic scale (Seca 899, SECA GmbH, Hamburg, Germany), and height was measured to the nearest 0.1 cm with a portable stadiometer (Seca 217, SECA GmbH, Hamburg, Germany). Body mass index (BMI, kg/m^2) was calculated, and children were classified as normal weight, overweight, or obese, based on criteria proposed by Cole et al. (Cole et al., 2000). Seasons were categorized as autumn (September–December), winter (January–March), and spring/summer (April–June).

2.3. Statistical analysis

Children's characteristics, PA, and SED were reported as frequencies, means, and standard deviations (SD), except for the number of valid days of accelerometer data, which was reported as median. To account for the clustering of observations within preschools, all analyses for continuous outcomes were performed using a three-level linear mixed model that included random intercepts for children and preschools (i.e., observations were clustered within children and children were clustered within preschools). For categorical outcomes, we used generalized estimating equations defining preschools as the cluster variable using an exchangeable correlation structure.

We performed two types of main analyses. First, we compared the amount of PA during preschool hours vs. time-out of care and on weekdays vs. weekend days. Second, we analysed sex, age, and overall MVPA as moderators of PA across settings/time of week by analysing interactions for setting/time of week according to those characteristics (e.g. sex*setting, age*setting, overall MVPA*setting, etc.), and we reported the associated p-values. Main effect estimates (β coefficients) and 95% confidence intervals (CI) were calculated separately for preschool hours, time out-of-care, weekdays, and weekend days. Interaction analysis was performed in two steps across both comparisons (preschool hours vs. time-out of care, weekdays vs. weekend days). First, we tested the interactions of sex*setting/age*setting (in the same model) and sex*time of week/age*time of week (in the same model), and second, we included the interaction of overall MVPA*setting/MVPA*time of week to the above-mentioned models.

PA was the outcome in all models, and all models were controlled for parental SES, accelerometer wear time (except for descriptive mean values), season, and BMI. Intraclass correlations (ICC) was calculated as the variance in PA explained by preschool divided by total variance. All analyses were performed using IBM SPSS v. 24 (IBM SPSS Statistics for Windows, Armonk, NY; IBM Corp., USA). $p < 0.05$ indicated statistically significant findings.

Table 1
Children's characteristics.

	Total sample N = 1109	Boys n = 572	Girls n = 537
Age (years) (mean ± SD)	4.7 (0.9)	4.8 (0.9)	4.7 (0.9)
Ethnicity of child			
Born in Norway	978 (97%)	503 (97%)	475 (97%)
Mother born in Norway	891 (89%)	461 (89%)	430 (88%)
Father born in Norway	884 (88%)	460 (89%)	424 (87%)
Age-specific weight status			
Normal	883 (81%)	470 (84%)	413 (78%)
Overweight	173 (16%)	76 (14%)	97 (18%)
Obese	28 (3%)	9 (2%)	19 (4%)
Parental education level[a]			
Upper secondary school	104 (10%)	52 (10%)	52 (10%)
University < 4 years	441 (42%)	223 (41%)	218 (43%)
University ≥ 4 years	504 (48%)	262 (49%)	242 (47%)
Parental income level[a]			
< 32,500 EUR	56 (6%)	28 (5%)	28 (6%)
32,500–62,000 EUR	619 (62%)	328 (64%)	291 (60%)
> 62,000 EUR	325 (32%)	161 (31%)	164 (34%)

All values are n (%) unless stated otherwise; SD, Standard deviation; weight status defined according to Cole et al., 2000. The study was conducted in Sogn og Fjordane county, Norway, between September 2015 and June 2016.

[a] Parental education level and yearly income: highest level for mother or father was used.

3. Results

3.1. Sample description

Of 1308 study participants, 1109 (85%) children provided valid accelerometer data and were included in the analyses (Table 1). The children had a median 13 valid days of PA registration in total (4–7 days, 4%; 8–11 days, 28%; and > 12 days, 68%); a median of 9 weekdays (3–4 days, 2%; 5–7 days, 15%; and > 8 days, 83%), and 3 weekend days (1 day, 8%; 2 days, 18%; and > 3 days, 74%), respectively. Compared to children who provided valid accelerometer data, those who did not (n = 199) were slightly younger than the included children ($p < 0.01$), and had parents with lower educational levels ($p < 0.05$). The included and excluded children did not differ regarding BMI, sex, or parental income levels. For child characteristics, see Table 1.

3.2. Physical activity levels across settings and time of week

Overall, children had a mean (SD) total PA level of 751 (199) cpm and spent 66 (21) min in MVPA per day. Children participated in more PA (all intensities) and less SED on weekdays compared to weekend days ($p < 0.01$) (Table 2). Fig. 1 illustrates how MVPA varied throughout an average week- and weekend day. There was a clear difference in pattern according to time of the week, with a peak of 7–8 min/h at 1 pm and 3 pm on weekdays, compared to generally lower levels and a less characteristic pattern on weekend days. When investigating the effect of preschool on children's PA levels, the specific preschool accounted for 5%–12% of the variance in children's PA and SED (ICC for full day/during preschool hours: TPA: 0.10/0.12; SED: 0.07/0.07; LPA: 0.12/0.12; MVPA: 0.05/0.06).

Most total PA and MVPA was accumulated during preschool hours, both in absolute values and values relative to accelerometer wear time, as illustrated in Fig. 2. Boys and girls spent, on average, 12% and 10% of their preschool day in MVPA, respectively. Moreover, 77% of children's total MVPA on weekdays was undertaken during preschool hours. However, after adjusting for wear time, MVPA only differed significantly between preschool hours and time out-of-care among boys ($p < 0.05$) (Table 2).

3.3. Moderation of patterns according to sex, age, and overall MVPA

Table 3 gives an overview of the results regarding moderation of patterns across settings and time of week for sex, age, and overall MVPA. For the interaction of sex*setting (i.e. preschool hours vs. time out-of-care), there were greater sex-differences during preschool hours compared to time out-of-care for total PA ($p < 0.05$), SED, LPA, and MVPA ($p < 0.001$). This indicated that preschool hours were associated with greater differences in PA between boys and girls relative to time spent out-of-care. Similarly, when testing the interaction sex*time of week (i.e. weekdays vs. weekend days), we found greater sex-differences during weekdays compared to weekend days, but only for LPA and SED ($p < 0.05$).

With regard to the interaction of age*setting, the difference in MVPA and SED between preschool hours and time out of care was greater in older children, with relatively more MVPA and less SED during preschool hours by increasing age ($p < 0.001$). Similarly, there was a significant interaction of age*time of week with greater difference MVPA and SED on weekdays than on weekend days in older children ($p < 0.001$, $p < 0.05$).

Interaction analyses of overall MVPA (regardless of setting and/or time of week) and setting (overall MVPA*setting) showed greater differences in both total PA, LPA, SED, and MVPA ($p < 0.001$) between preschool hours and time out-of-care with regard to higher levels of overall MVPA. Children with higher levels of overall MVPA had more total PA and MVPA, and less SED and LPA, during preschool hours compared to time out-of-care relative to children with lower levels of overall MVPA. Similarly, the interactions of overall MVPA and time of week (overall MVPA*time of week) showed greater differences in MVPA and SED ($p < 0.001$) between weekdays and weekend days according to higher levels of MVPA, with relatively more MVPA and relatively less SED on weekdays compared to weekend days.

4. Discussion

Children spent more time in MVPA during preschool hours than during time out-of-care (NS difference in girls). Similarly, children were more physically active and less sedentary on weekdays than on weekend days. MVPA levels during preschool hours, relative to time out-of-care, were higher in boys, older children, and highly active children compared to girls, younger children, and children with lower levels of overall MVPA. Therfore, with regards to MVPA, some groups of children appear to benefit more from the preschool environment than others.

The preschool is important for children's MVPA in two ways. First, it is important in terms of actual time spent in MVPA during preschool hours because children spend a large amount of time in this arena throughout the week. Second, it is important in terms of relative amounts of MVPA adjusted for time, regardless of how much time children spent in preschool, as this arena promoted MVPA more than the out-of-care environment (Fig. 2). We observed peaks in MVPA at around 1:00 pm and 3:00 pm on weekdays (Fig. 1). This corresponded well with commonly scheduled outdoor-time in most of the preschools involved in our study, in which is associated with higher MVPA levels (Truelove et al., 2018).

Our findings showing higher activity levels during preschool hours compared to time out-of-care are in line with three previous studies from the UK, Denmark, and Sweden (Hesketh et al., 2015; Moller et al., 2017; Berglind and Tynelius, 2017), but in contrast to results from the US and Australia (Van Cauwenberghe et al., 2012; O'Dwyer et al., 2014; O'Neill et al., 2016). The conflicting results between studies could be explained by heterogeneity between samples, the amount of outdoor time, differences in policies or preschool environment, and/or in childcare attendance (e.g. hours per day in preschool), possibly affecting levels of PA. In Norway in general, as in the present study sample, almost all children attend preschool full time (97% of 3–5 year

Table 2

Mean values (SD) and differences (β, [95% CI]) in wear time, SED, and time in PA between weekdays and weekend days, and between preschool hours and time out-of-care.

	Time of week			Setting		
	Weekdays	Weekend days	Difference adjusted for wear time	Preschool hours[a]	Time out-of-care[b]	Difference adjusted for wear time
	Mean (SD)		β (95% CI)	Mean (SD)		β (95% CI)
Total (n = 1109)						
Wear time (min/day)	717 (44)	652 (66)	65 (61, 69)[**]	407 (14)	163 (19)	244 (243, 246)[**]
TPA (cpm)	753 (199)	719 (261)	57 (39, 75)[**]	823 (240)	633 (225)	102 (−41, 244)
SED (min/day)	347 (55)	333 (63)	−22 (−25, −18)[**]	179 (33)	91 (17)	−9 (−24, 7)
LPA (min/day)	298 (44)	257 (46)	16 (13, 18)[**]	183 (29)	59 (11)	−1 (−13, 11)
MVPA (min/day)	68 (22)	59 (23)	6 (5, 8)[**]	43 (15)	13 (5)	8 (1, 15)[*]
Boys (n = 572)						
Wear time (min/day)	720 (44)	659 (65)	61 (56, 67[**]	407 (14)	164 (1)	243 (241, 245)[**]
TPA (cpm)	787 (203)	748 (254)	59 (34, 84)[**]	867 (255)	655 (16)	142 (−85, 369)
SED (min/day)	341 (54)	332 (60)	−22 (−27, −18)[**]	172 (32)	91 (17)	−10 (−32, 13)
LPA (min/day)	301 (42)	260 (45)	16 (13, 20)[**]	186 (28)	59 (11)	−4 (−20, 13)
MVPA (min/day)	74 (23)	64 (24)	6 (4, 8)[**]	47 (16)	14 (5)	12 (1, 22)[*]
Girls (n = 537)						
Wear time (min/day)	713 (43)	644 (67)	70 (64, 75)[**]	407 (14)	162 (20)	246 (244, 248)[**]
TPA (cpm)	718 (188)	689 (264)	54 (28, 80)[**]	776 (213)	610 (212)	43 (−128, 214)
SED (min/day)	354 (50)	335 (66)	−21 (−25, −16)[**]	186 (32)	91 (17)	−3 (−24, 18)
LPA (min/day)	293 (46)	253 (47)	14 (11, 18)[**]	181 (30)	58 (11)	0 (−17, 17)
MVPA (min/day)	62 (20)	53 (21)	6 (4, 8)[**]	39 (13)	12 (5)	2 (−7, 11)

SD, Standard deviation. Unadjusted values are reported as mean (SD). The β coefficient represents the difference in wear time, min spent sedentary (SED), in light physical activity (LPA), and in moderate-to-vigorous physical activity (MVPA) per day, and the difference in total physical activity (TPA [cpm]), on weekdays vs. weekend days and during preschool hours vs. time out-of-care. Results from a three-level random intercept model adjusted for sex, age, BMI, parental education (highest level of mother or father), parental income level (highest yearly income of mother or father), season, and accelerometer wear time (min per day) when wear time was not the outcome, with “preschool” and “child” as cluster effects. The study was conducted in Sogn og Fjordane county, Norway, between September 2015 and June 2016.

[a] PS hours: Preschool hours (08:30 am–15:29 pm) on weekdays.

[b] Time out-of-care (morning 06:00–08:29 am and afternoon 15:30–23:59 pm on weekdays).

[*] $p < 0.05$.

[**] $p < 0.01$.

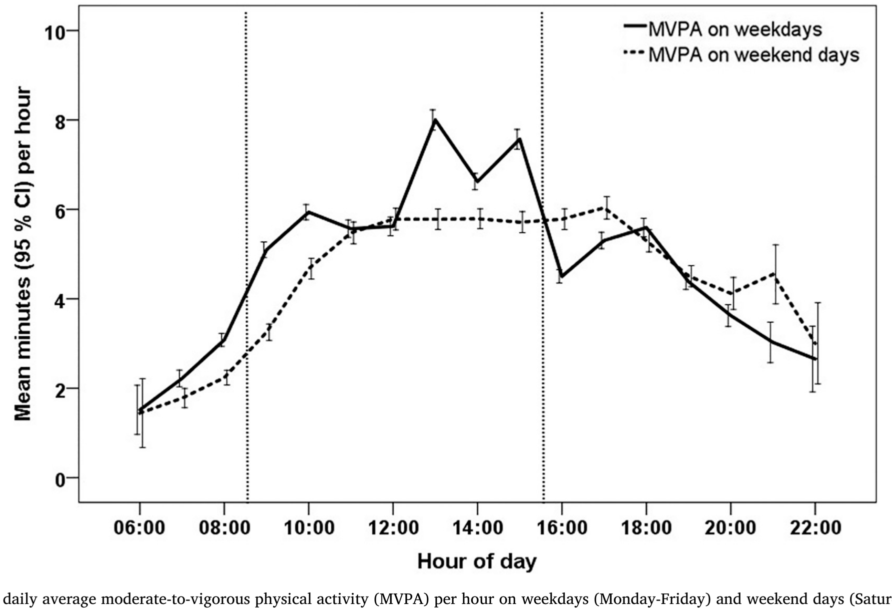

Fig. 1. Children's daily average moderate-to-vigorous physical activity (MVPA) per hour on weekdays (Monday-Friday) and weekend days (Saturday and Sunday). The vertical lines indicate preschool hours, defined as the hours between 08:30 am and 3:30 pm on weekdays. The study was conducted in Sogn og Fjordane county, Norway, between September 2015 and June 2016.

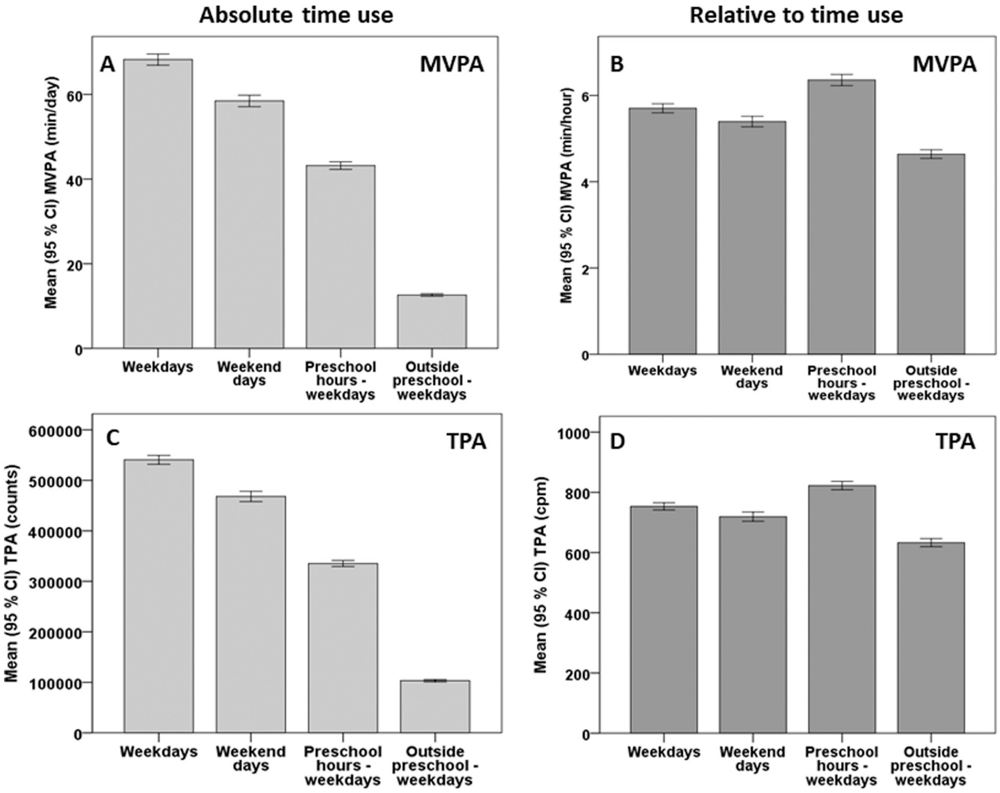

Fig. 2. Children's average MVPA (A, B) and total PA (TPA) (C, D) in absolute values (A, C) and values relative to accelerometer wear time (B, D). MVPA reported as minutes per day/minutes per hour, and total PA reported as counts/counts per minute. The study was conducted in Sogn og Fjordane county, Norway, between September 2015 and June 2016.

olds on a national level), i.e. ≥33 h per week (Statistics Norway, 2017). As the results of the present study are in line with results from other north-west European countries, we considered that differences in practice and attendance, for example in the US or Australia, are factors explaining the conflicting results, although additional comparative studies is needed to conclude in this matter.

Another aspect of the observed differences in setting-specific PA between studies is the variability in preschool environments within the same country or geographical area, which can lead to an inaccurate interpretation of the preschool's role for PA. In the present study, the specific preschool explains 5% of the variance in MVPA and 10% of the variance in total PA (cpm) (ICC). These percentages are in line with the median ICC reported in a systematic review by Finch et al. (Finch et al., 2016), and comparable with other European studies reporting on these specific variables (Hesketh et al., 2015; Olesen et al., 2014). In contrast, some US studies have shown that a specific preschool can account for up to 47% of the variance in children's MVPA (Finn et al., 2002; Pate et al., 2004). A low ICC in studies involving European countries may indicate that preschools in Europe are rather similar in terms of environmental factors and culture.

Substantial evidence shows that boys in general are more physically active and less sedentary than girls, and that sex-differences in PA are already present in preschool-aged children (Tonge et al., 2016). Our results support these conclusions, with a further suggestion that sex-differences in PA are also dependent on setting. We found that boys undertook relatively more PA and less SED when in preschool than girls (e.g. a difference in MVPA for preschool hours vs. time out-of-care of 12 min for boys (p = 0.05) vs. 2 min for girls, NS difference) (Table 2). Moller et al. and Hesketh et al. showed similar findings in terms of total PA (cpm), with boys exhibiting higher levels when in preschool compared to girls; however, they did not test interactions relative to time out-of-care (Hesketh et al., 2015; Moller et al., 2017).

As previously proposed by Hesketh et al., we believe that the opportunities for high-intensity play in the preschool environment might suit boys better than girls regarding sex-related activity preferences (Hesketh et al., 2015). The Nordic preschool model is characterized with a high focus on "learning through play" and children spend a considerable amount of time outdoors (Einarsdottir, 2013); therefore, we hypothesize that free outdoor play, in terms of MVPA, was more favourable to boys than to girls. Boys often prefer a more intensive, rough-and-tumble-play (Pellegrini and Smith, 1998) pattern than girls, who tend to prefer social, often light-intensity play (Barbu et al., 2011) that may vary less between the home and childcare environments, and could explain the observed differences in setting-specific MVPA between boys and girls. In contrast, Berglind and Tynelius found an opposite trend in their study of 4-year-old Swedish children. Their results showed that levels of SED and MVPA between the sexes were most apparent during time out-of-care on weekdays, indicating that girls are relatively more active and less sedentary than boys when in preschool, and less active and more sedentary during time out-of-care (Berglind and Tynelius, 2017).

To our knowledge, this is the first study to investigate interactions of

Table 3
Interactions between settings and time of week and SED and sex, age, and overall MVPA levels.

	N = 1109, β (95% CI)			
	Total PA (cpm)	SED	LPA	MVPA
	Preschool hours vs. time out-of-care			
Sex*setting	$p = 0.013$	$p < 0.001$	$p < 0.001$	$p < 0.001$
Sex differences in preschool hours (girls vs. boys)	−77.9 (−105.5, −50.2)**	12.6 (8.9, 16.3)**	−5.4 (−8.3, −2.5)**	−7.3 (−9.0, −5.7)**
Sex differences in out-of-care (girls vs. boys)	−37.4 (−63.5, −11.2)**	1.5 (0.1, 3.0)*	−0.1 (−1.2, 1.1)	−1.4 (−2.0, −0.9)**
Age*setting	$p = 0.259$	$p < 0.001$	$p = 0.524$	$p < 0.001$
Preschool hours (change/year)	47.1 (30.5, 63.6)**	−1.9 (−4.1, 0.4)	−3.1 (−4.8, −1.4)**	5.1 (4.1, 6.1)**
Time out-of-care (change/year)	40.0 (23.7, 56.2)**	- 0.6 (−1.5, 0.3)	−0.7 (−1.4, 0.01)	1.3 (1.0, 1.6)**
Total MVPA*setting	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$
Preschool hours (change/min increase in total MVPA)	9.2 (8.7, 9.7)**	−1.0 (−1.1, −0.9)**	0.3 (0.3, 0.4)**	0.7 (0.6, 0.7)**
Time out-of-care (change/min increase in total MVPA)	7.3 (6.7, 7.9)**	−0.3 (−0.4, −0.3)**	0.2 (0.1, 0.2)**	0.2 (0.2, 0.2)**
	Weekdays vs. weekend days			
Sex*time of week	$p = 0.402$	$p = 0.026$	$p = 0.043$	$p = 0.112$
Sex differences in weekdays (girl vs. boy)	−57.4 (−80.0, −34.8)**	15.1 (9.0, 21.1)**	−5.2 (−10.0, −0.4)*	−9.9 (−12.3, −7.5)**
Sex differences in weekend days (girl vs. boy)	−54.2 (−84.5, −23.9)**	10.32 (4.0, 16.6)**	−1.3 (−6.2, 3.6)	−8.8 (−11.4, −6.2)**
Age*time of week	$p = 0.671$	$p = 0.016$	$p = 0.315$	$p < 0.001$
Weekdays (change/year)	45.7 (30.7, 58.6)**	−2.6 (−6.3, 1.1)	−4.8 (−7.8, −1.8)**	7.6 (6.1, 9.1)**
Weekend days (change/year)	44.4 (26.3, 62.5)**	1.4 (−2.4, 5.1)	−6.5 (−9.4, −3.5)**	5.6 (4.0, 7.1)**
Overall MVPA*time of week	$p = 0.089$	$p < 0.001$	$p = 0.016$	$p < 0.001$
Weekdays (change/min increase in overall MVPA)	8.7 (8.4, 9.1)**	−1.7 (−1.8, −1.6)**	0.7 (0.5, 0.8)**	1.0 (1.0, 1.1)**
Weekend days (change/min increase in overall MVPA)	8.0 (7.3, 8.7)**	−1.4 (−1.5, −1.2)**	0.5 (0.4, 0.6)**	0.9 (0.8, 0.9)**

Highlighted p-values are derived from interaction analysis. The β coefficient (95% CI) represents the difference in min per day spent sedentary (SED), in light physical activity (LPA), and in moderate-to-vigorous physical activity (MVPA), and the difference in total physical activity (cpm), compared to the reference category (girls vs. boys) or as a change (per year; per minute increase in overall MVPA), for the associated setting/time of week. Final results from a three-level random intercept model adjusted for sex, age, BMI, parental education (highest level of mother or father), parental income level (highest yearly income of mother or father), season, and accelerometer wear time. Overall MVPA, mean all day MVPA regardless of setting or time of week. The study was conducted in Sogn og Fjordane county, Norway, between September 2015 and June 2016.

* $p < 0.05$.

** $p < 0.01$.

setting and time of week to age and overall MVPA levels within the preschool population. Despite relatively small differences, we found that the difference in MVPA and SED between preschool hours and time out-of-care was larger for older vs. younger children, in terms of relatively more MVPA and less SED when in preschool. These findings suggest that the age-related development in preschoolers' MVPA is linked more to factors within the preschool environment than to the out-of-care (home) environment. Further, it appears that the preschool arena affects children's MVPA increasingly with age, implying that older children (e.g. 5- to 6-year-olds) benefit more from this environment in terms of high-intensity activities than younger children (e.g. 3- to 4-year-olds). Additionally, we investigated whether PA in different settings was dependent on children's overall levels of MVPA (regardless of setting/time of week), and found that children with higher levels of overall MVPA had more total PA and MVPA during preschool hours compared to time out-of-care relative to children with lower levels of overall MVPA. These results suggest that highly active children undertake even more MVPA during preschool hours than children with lower overall MVPA levels. This finding is interesting as Moller et al. reported that less active children were substantially and consistently less active compared to highly active children, irrespective of the context (Moller et al., 2017). However, they did not investigate the relative difference between PA among children with high- or low-activity levels during preschool hours compared to time out-of-care.

Although previous studies have suggested that children's PA levels are determined mostly by genetic factors (Pate et al., 2004), our results and those of others (Hesketh et al., 2015; Van Cauwenberghe et al., 2012; O'Dwyer et al., 2014; Moller et al., 2017; Berglind and Tynelius, 2017; O'Neill et al., 2016) suggest that setting-specific factors (e.g. social and/or environmental factors) exert an important influence on children's PA levels which, in turn, are dependent on individual factors such as sex and age.

As PA levels are known to decrease over time in school-aged children and adolescents (Cooper et al., 2015), the preschool years are a critical period to ensure sufficient levels of PA throughout childhood (Goldfield et al., 2012). Previous studies have highlighted the home environment as an important arena for PA promotion in preschool-aged children, as this seems to be an arena with great potential to increase MVPA levels (Hesketh et al., 2015; Moller et al., 2017; Berglind and Tynelius, 2017). The lower MVPA levels at home compared to preschool hours showed herein, is consistent with this view. However, although we recognize the home environment as an important arena for young children's PA, we consider the preschool arena as an ideal setting for PA promotion because of its unique opportunity for structured PA for all children, irrespective of children's characteristics and parents' behaviours, attitudes, resources, and socio-economic background.

5. Strengths and limitations

The present study had a large sample size, a wide age range, a high response rate, good compliance with the accelerometer protocol, and a long PA monitoring period, which are major strengths. Due to the considerable week-by-week variability observed when measuring PA by accelerometry in preschool children (Aadland and Johannessen, 2015), a long registration period (> 7 days) will increase the reliability of the accelerometer measurements (Aadland and Johannessen, 2015) and, thus, increase the validity of the study conclusions. Therefore, the 14-day PA monitoring protocol applied herein is considered an important strength of the study.

Accelerometer data are, however, not without limitations (Cain et al., 2013). In addition to challenges relating to cut-points and other methodological considerations, the accelerometer do not correctly capture certain activities (e.g. cycling or swimming). Furthermore, the accelerometer does not provide information about the type of PA or the context in which the PA was conducted, which would have been valuable information when studying PA patterns within different settings.

Another limitation of the present study is the use of standardized times for defining in- and out-of-preschool, which might have introduced some misclassification of time use. However, although some random errors may have been introduced, estimates were based on the means of attendance; thus, we consider that the results were not biased through our choice of time categories. Further, the average parental educational level among the included children was higher than among the excluded children, and almost all the participating children were born in Norway. This means that caution should be exercised in generalising the results to populations comprising ethnic minorities or populations with lower SES, including other Norwegian populations.

6. Conclusion

The present study adds to the limited evidence on how different settings influence preschoolers' PA, and highlights the importance of the preschool arena for children's MVPA. Norwegian preschoolers are overall more physically active during preschool hours than during time out-of-care and, similarly, more active on weekdays compared to weekend days. Children's PA levels are further dependent on individual factors, such as sex, age, and overall MVPA levels. Our results indicate that the preschool environment stimulates boys, older children, and highly active children more successfully in terms of higher MVPA levels. Awareness of these differences and greater encouragement for girls, younger preschoolers, and less active children to participate in moderate-to-high-intensity activities during preschool hours may, therefore, be warranted.

Conflicts of interest

None.

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STUDY III

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PHYSICAL ACTIVITY, HEALTH AND EXERCISE

The multivariate physical activity signature associated with fundamental motor skills in preschoolers

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ABSTRACT

Physical activity (PA) is essential for development of fundamental motor skills (FMS) in children, but it is uncertain which PA intensities are most influential. A limitation to current evidence is the reliance on analytic approaches that cannot handle collinearity. The aim of this study was to determine the PA signature related to FMS in preschoolers, by investigating the association pattern for the whole spectrum of PA intensities using multivariate pattern analysis. We used a sample of N = 1081 Norwegian preschoolers (4.7 yr; 52% boys) who provided valid accelerometer (ActiGraph GT3X+) and FMS data (TGMD-3, modified version). We created 33 PA variables (from 0–100 to ≥15,000 counts per minute [cpm]), and used partial least squares regression to analyse the associations between PA and FMS, after controlling for potential covariates. PA was positively associated with locomotor- and object control skills (explained variances for vertical axes; R^2 = 9.7% and 3.9%, respectively). The strongest associations were found for PA between 5000–8000 cpm. No association pattern was found for PA and balance skills. This study is the first to determine the multivariate PA intensity signature related to FMS. This approach shows that PA within the vigorous range is strongest related to FMS in preschoolers.

Abbreviations: FMS: fundamental motor skills; PA: Physical activity; TPA: total physical activity; SED: Sedentary behaviour; LPA: Light physical activity; MPA: Moderate physical activity; VPA: Vigorous physical activity; MVPA: Moderate-to-vigorous physical activity; Min: minutes; cpm: counts per minute; SD: standard deviation; SES: Socioeconomic status; BMI: Body Mass Index.

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Multivariate pattern analysis; motor development; gross motor skills; motor competence; intensity spectrum; partial least squares regression

Introduction

Fundamental motor skills (FMS) in children has gained credence in the last decade as an important correlate of physical activity (PA) and other health related behaviours and outcomes (Robinson et al., 2015). The positive relationship between FMS and PA in childhood is well documented (Holfelder & Schott, 2014; Logan, Kipling Webster, Getchell, Pfeiffer, & Robinson, 2015), and is likely to be bidirectional (Stodden et al., 2008). FMS' are considered the "building blocks" of more advanced, complex movements (Logan, Ross, Chee, Stodden, & Robinson, 2018), and children develop their FMS through engagement in PA (Figueroa & An, 2017). From an early age, an adequate level of FMS is necessary to move and control the body to enable participation in physically active play (Cools, De Martelaer, Samaey, & Andries, 2009). Therefore, the preschool years are vital for both PA (Carson et al., 2017; Goldfield, Harvey, Grattan, & Adamo, 2012) and for FMS – as children develop competence in many fundamental movements during this period (Fisher et al., 2005).

The relationship between PA and FMS are hypothesised to differ according to a child's age and developmental stage (Barnett et al., 2016; Stodden et al., 2008), as well as by PA intensity and by FMS domain (Figueroa & An, 2017). However, only a few studies have examined the relationship between PA and FMS in preschool children. These studies have shown weak to moderate positive relationships, but findings are inconsistent (Figueroa & An, 2017; Robinson et al., 2015). Furthermore, the majority of studies investigating relationships between objectively measured PA and FMS in preschoolers have primarily focused on associations for moderate-to-vigorous PA (MVPA). This narrow focus causes a substantial loss of information from accelerometry as it ignores the possible influence of light PA (LPA), moderate PA (MPA) and vigorous PA (VPA), and thus increase susceptibility to residual confounding for the analysed variables (van der Ploeg & Hillsdon, 2017).

A systematic literature review (Figueroa & An, 2017) supports a stronger, favourable association of MVPA over LPA for FMS in preschoolers, although a recent Finnish study did not find any association between MVPA and FMS among 5–6 year olds (Matarma et al., 2018). Furthermore, evidence is conflicting regarding the role of LPA for FMS, as some studies find a favourable association (Burgi et al., 2011; Foweather et al., 2015), and others do not (Fisher et al., 2005; Williams et al., 2008). Few studies have investigated the association between sedentary behaviour (SED) and FMS; however, some studies have demonstrated that lower SED is associated with better FMS (Lopes, Santos, Pereira, & Lopes, 2012; Williams et al., 2008; Wrotniak, Epstein, Dorn, Jones, & Kondilis, 2006). A recent longitudinal study investigating the prospective associations between FMS and different PA intensities in adolescents

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found positive relationships between FMS at baseline and total PA, MPA, and MVPA after two years, but no relationship for LPA (Lopes et al., 2019).

In addition to inconclusive results among studies, the interpretation and comparison of findings regarding possible PA intensity-specific influences across studies are hampered by great variability in accelerometer cut points used (Cain, Sallis, Conway, Van Dyck, & Calhoon, 2013; Poitras et al., 2016), which leads to the capturing of somewhat different PA intensities. Therefore, the activities and PA-intensities captured by accelerometer differ among studies, which in turn leads to uncertainty regarding which PA intensities are strongest related to FMS. This challenge can be solved by analysing the intensity spectrum as a whole, irrespective of pre-defined cut points and selected PA intensity ranges, as proposed by Aadland et al. (Aadland, Kvalheim, Anderssen, Resaland, & Andersen, 2018).

Because the different PA intensity variables derived from accelerometry are strongly correlated, common statistical methods (i.e., multiple linear regression) are unsuited to explore the association pattern across the PA spectrum with a given outcome. Therefore, we need novel statistical methods that can overcome this challenge (Aadland et al., 2018; Saunders et al., 2016). Aadland et al. recently solved the collinearity challenge by applying multivariate pattern analysis to determine the PA intensity signature associated with metabolic health in schoolchildren (Aadland et al., 2018). Multivariate pattern analysis can handle completely collinear variables (Aadland et al., 2018; Friedewald, Levy, & Fredrickson, 1972; Rajalahti et al., 2010; Rajalahti & Kvalheim, 2011), and is therefore well suited to study associations for strongly correlated accelerometry data. Because it allows for a more integrated and valid interpretation of findings, it is a promising approach in the field of PA epidemiology (Aadland et al., 2018). To the best of our knowledge, this approach has not yet been applied to explore associations between PA and FMS.

By using the whole PA intensity spectrum, the aim of the present study was to determine the intensity pattern that was associated with FMS in preschool aged children.

Materials and methods

Study design and recruitment of participants

The present study is a cross-sectional analysis based on data from The Sogn og Fjordane Preschool Physical Activity Study (PRESPAS). The study was conducted in a rural area in western Norway, between September 2015 and June 2016. Out of 26 possible municipalities in the county of Sogn og Fjordane, 15 were invited to participate in the study. Municipalities were strategically selected based on average parental education level, population size, geographical location, average number of children per preschool, and average number of children per preschool teacher. One municipality chose not to take part in the study. All preschools in the remaining 14 municipalities were invited. In total, 68 of 74 invited preschools participated in the study. All children born during 2010–2012 within the participating preschools were invited. In total, 1308 of 1925 possible children took part in the study (response rate, 68%).

Parents of all participating children received oral and written study information and provided written consent prior to testing. Children were provided with an explanation of the measurements according to their level of understanding. The Norwegian Center for Research Data (NSD) approved the study (reference number: 39,061).

Procedures

Physical activity measurement

PA was measured using the ActiGraph GT3X+ accelerometer (ActiGraph, LLC, Pensacola, Florida, USA) (John & Freedson, 2012). Accelerometers were attached to a participating child's right hip, and children were instructed to wear the monitor at all times for 14 consecutive days, except during water-based activities and while sleeping (at night). Accelerometers were initialised with a sampling rate of 30 Hz and analysed using 1-second epochs using the KineSoft software (KineSoft version 3.3.80, Loughborough, UK). Periods of ≥20 min of zero counts were defined as non-wear time (Esliger, Copeland, Barnes, & Tremblay, 2005). Our criterion for a valid day was ≥480 min of wear time accumulated between 06:00 and 24:00 hours. We included all children who provided ≥3 weekdays and ≥1 weekend day of valid PA data in the analysis.

Outcomes for the descriptive statistics and bivariate correlation analyses were total PA (TPA) (counts per minute [cpm]) and intensity-specific PA, reported as sedentary behaviour (SED) (≤100 cpm), light-intensity PA (LPA) (101–2295 cpm), moderate-intensity PA (MPA) (2296–4011), vigorous-intensity PA (VPA) (≥4012 cpm), and MVPA (min/day) (≥2296 cpm), as proposed by Evenson, Catellier, Gill, Ondrak, & McMurray, (2008) (vertical axis only). We further created 33 PA variables of total time (min/day) to capture movement in narrow intensity intervals throughout the spectrum from all axes (vertical, antero-posterior, and medio-lateral); 0–99, 100–249, 250–499, 500–999, 1000–1499, 1500–1999, 2000–2499, 2500–2999, 3000–3499, 3500–3999, 4000–4499, 4500–4999, 5000–5499, 5500–5999, 6000–6499, 6500–6999, 7000–7499, 7500–7999, 8000–8499, 8500–8999, 9000–9499, 9500–9999, 10,000–10,499, 10,500–10,999, 11,000–11,499, 11,500–11,999, 12,000–12,499, 12,500–12,999, 13,000–13,499, 13,500–13,999, 14,000–14,499, 14,500–14,999, and ≥ 15,000 cpm.

Fundamental motor skills

To measure FMS, we developed a test battery guided by the "Test of Gross Motor Development 3" (TGMD-3) (Ulrich, 2019) and the Preschooler Gross Motor Quality Scale (PGMQ) proposed by Sun et al. (Sun, Zhu, Shih, Lin, & Wu, 2010). TGMD-3 is designed for children aged 3–10 years, and originally based on observation of children's movements across 13 tasks within the two domains: locomotion (run, skip, slide, gallop, hop, and horizontal jump) and ball/object control (hereafter referred to as "object control") (overhand throw, underhand throw, catch, dribble, kick, one-hand strike, and two-hand strike). We modified this test battery to reduce the researcher and participant burden, and at the same time cover the three main domains of FMS by including balance skills (Gallahue & Cleland-Donnelly, 2003; Sun et al., 2010). We therefore included six movement tasks from the TGMD-3 (run, horizontal jump, hop, catch, overhand throw, and kick), in addition to three movement tasks within the balance domain (single leg standing, walking line forward, and walking line backward) from the PGMQ (Gallahue & Cleland-Donnelly, 2003; Sun et al., 2010), in our assessment of FMS. The specific skills were selected based on experts' opinion on their relevance (e.g., some of the movement tasks in the TGMD-3, like the baseball strike and bouncing a ball, are less common and therefore less relevant in assessments of Norwegian children), and variety (e.g., including object control skills related to both hands and feet, and adding both static and dynamic balance tests) in terms of broadly capturing children's skills within the three domains.

Children were evaluated in small groups (4–5 children) during preschool hours, and were asked to perform the nine movement tasks in a safe environment with enough space to move freely. A familiar preschool teacher was present at all times. Each child performed each skill twice and skills were completed in a standardised order, taking approximately 30 minutes per group. The test teams consisted of one instructor who provided a verbal description and demonstration of the required skill, while a separate assessor observed and scored the performance. We administered the skills according to TGMD-3 (locomotor- and object control skills) and PGMQ (balance skills) protocols. Children were scored quantitatively based on a qualitative evaluation of whether the child did or did not demonstrate specific process criteria for each skill based on the original scoring procedures for TGMD-3 and PGMQ (marked as either absent: "0" or present: "1") (Sun et al., 2010; Ulrich, 2019). The children had two trials per task, and the score from trial 1 and 2 were summed, thus – providing a score of 0 to 2 points per criteria. The calculation of item- and domain scores was, however, different from the original procedures: The criteria scores were averaged for each item and each domain. In contrast to the original scoring protocols for TGMD-3/PGMQ (Sun et al., 2010; Ulrich, 2019) that uses sum scores, our procedure ensures similar weight to all skills within the domains, independent of the number of assessed criteria, all with a range from 0 to 2 points (a mean score closer to "2" equals to more proficiency in the task or domain).

Prior to the data collection, all raters performed thorough training in how to instruct and score children in the different movement tasks. Inter-rater reliability (ICC) was 0.90 for the locomotor tasks, 0.74 for the object control tasks, and 0.86 for the balance tasks.

Anthropometrics

We assessed children's body weight and height during preschool hours. Body weight was measured to the nearest 0.1 kg using an electronic scale (Seca 899, SECA GmbH, Hamburg, Germany), and height was measured to the nearest 0.1 cm with a portable stadiometer (Seca 217, SECA GmbH, Hamburg, Germany). Body mass index (BMI, kg/m^2) was calculated and used as a continuous variable in the association analysis. Children were additionally classified as normal weight, overweight, or obese based on criteria proposed by Cole et al. (Cole, Bellizzi, Flegal, & Dietz, 2000) for descriptive purposes.

Other covariates

Children's sex, age, and parental socioeconomic status (SES, based on the highest education level and the highest yearly income of mother or father) were assessed using a questionnaire completed by the child's mother and/or father. Seasons were categorised as autumn (September-December), winter (January-March), and spring/summer (April-June).

Statistical analysis

Children's characteristics, FMS, PA, and SED were reported as frequencies, means, and standard deviations (SD), except for the number of valid days of accelerometer data, which was reported as the median. We tested for differences in characteristics between included and excluded children, by age, and between boys and girls, using a two-level linear mixed model including random intercepts for preschools for continuous outcomes, and a generalised estimating equation defining preschools as the cluster variable using an exchangeable correlation structure for categorical outcomes. All analysis were adjusted for the following covariates: age, sex, BMI, accelerometer wear time and season (when investigating associations to PA), FMS score person (when investigating associations to FMS), and with preschool as a random effect. In addition, we performed sensitivity analysis including adjustment for parental income- and education level; however, as these variables had no impact on the conclusions, parental SES was not adjusted for in the final analysis.

Interrelationships between all 33 PA variables, and between domain-specific FMS scores, were tested using unadjusted, bivariate correlation analyses. Prior to the multivariate pattern analysis, we performed linear mixed model regression analyses with all FMS variables as dependent variables in separate models, including all covariates as independent variables, to obtain residuals from these models to adjust the outcomes for these variables and remove confounding. Associations between PA and FMS were thereafter determined using Pearson's r and multivariate pattern analysis as shown previously (Aadland et al., 2018).

Partial least squares (PLS) regression analysis (Wold, Ruhe, Wold, & Dunn, 1984) were used to determine the multivariate PA signature of the FMS variables (outcome variables), including all PA variables as explanatory variables. PLS regression decomposes the explanatory variables into orthogonal linear combinations, while simultaneously it maximises the covariance with the outcome variable. Thus, in contrast to ordinary least squares regression, PLS regression is able to handle completely collinear variables.

Monte Carlo resampling (Kvalheim, Arneberg, Grung, & Rajalahti, 2018) with 100 repetitions was used to optimise the predictive performance of the models by randomly keeping 50% of the subjects as an external validation set when estimating the models. For each validated PLS regression model, a single predictive component was subsequently calculated by means of target projection (Kvalheim & Karstang, 1989; Rajalahti & Kvalheim, 2011). By this transformation, all the predictive variance in the intensity spectrum related to FMS is expressed in a single intensity vector. Selectivity ratios (SRs) was determined as the ratio of this explained predictive variance to the total variance for each PA intensity variable (Rajalahti et al., 2009, 2009). The results are displayed in an SR plot indicating positive or negative associations with FMS, in addition to the models' explained variances (R^2). Confidence intervals were constructed around each SR and used to assess the significance of the SR for each PA variable. We analysed the sample as a whole, and further performed sensitivity analyses according to sex and age (median split), pattern associations are reported as Pearson's r.

Multivariate pattern analyses were performed by means of the commercial software Sirius version 11.0 (Pattern Recognition Systems AS, Bergen, Norway). All other analyses were performed using IBM SPSS v. 24 (IBM SPSS Statistics for Windows, Armonk, NY; IBM Corp., USA). $p < 0.05$ indicated statistically significant findings.

Results

Children's characteristics

Of the 1308 participating children, 1081 (83%) children provided valid data of PA, FMS, and the included covariates and were included in the analyses (Table 1). Compared to children who provided valid data, those who did not (n = 227) had parents with lower educational levels ($p < 0.05$). The included and excluded children did not differ with regard to sex, age, BMI, or parental income levels.

The children had a median of 13 valid days of PA registration (≤7 days: 5 %; 8–11 days: 28%; ≥12 days: 67%). Both total PA, MVPA and FMS increased by age ($p < 0.001$), and LPA decreased by age ($p < 0.05$). There were no association between SED and age ($p = 0.436$). Boys accumulated more total PA, LPA, and MVPA, and less SED, compared to girls (all $p < 0.001$). Further, boys scored significantly higher on object control skills than girls did ($p < 0.001$), while girls scored better on locomotor- and balance skills than boys ($p < 0.001$).

Table 1. Children's characteristics.

	Total sample N=1081	Boys n=555	Girls n=526
Demography			
Age (years) (mean ± SD)	4.7 (0.9)	4.8 (0.9)	4.7 (0.9)
Anthropometry			
BMI (kg/m^2) (mean ± SD)	16.2 (1.4)	16.2 (1.3)	16.2 (1.5)
Age-specific weight status			
Normal	82 %	85 %	79 %
Overweight	15 %	14 %	18 %
Obese	3 %	1 %	3 %
Socioeconomic status			
Parental education level[a]			
Upper secondary school	21 %	21 %	20 %
University <4 years	26 %	26 %	26 %
University ≥4 years	53 %	53 %	54 %
Physical activity			
Wear time (min/day)	702 (50)	706 (50)	697 (49)
Total PA (cpm)	722 (197)	755 (197)	687 (190)
SED (min/day)	485 (42)	480 (42)	490 (41)
LPA (min/day)	142 (20)	147 (20)	137 (18)
MPA (min/day)	36 (7)	38 (7)	33 (6)
VPA (min/day)	35 (11)	38 (12)	33 (11)
MVPA (min/day)	71 (17)	75 (18)	66 (16)
FMS[b]			
Locomotor	1.3 (0.4)	1.3 (0.4)	1.3 (0.4)
Object control	1.2 (0.3)	1.3 (0.4)	1.1 (0.3)
Balance	1.4 (0.4)	1.4 (0.4)	1.5 (0.4)

Values reported as n (%) or mean ± SD, Standard deviation; BMI, Body mass index; weight status defined according to Cole et al., 2000. [a]Parental education level: highest level for mother or father was used. [b] FMS: Fundamental motor skills; possible mean score between 0–2 per domain (a mean score closer to "2" equals to more proficiency in the task or domain).

Bivariate correlations

Table 2 shows associations for intensity-specific PA (TPA, LPA, MPA, VPA, and MVPA) and SED with FMS. We found that TPA, MPA, VPA, and MVPA were positively associated with locomotor- and object control skills ($p < 0.001$). No associations were found with balance skills. The strongest association was found for VPA and MVPA with locomotor skills (r = 0.26–0.27). Further, with reference to Table 2, FMS were not associated with LPA whereas SED was negatively associated with both locomotor- and object control skills, but not with balance skills.

When testing inter-relationships among the 33 PA variables, we found that time spent in the 0–99 cpm intensity interval correlated negatively with all other variables, and that the strongest correlations were found with time spent in intensity intervals from 1000 to 3999 cpm (r = −0.36 to −0.39). All variables, excluding the 0–99 cpm intensity interval, correlated strongly with the most proximal variables (r ≥ 0.95). Correlations weakened gradually for more distal variables, but were all positive. For FMS, all three domains were highly correlated (r = 0.46–0.63, $p < 0.001$), with strongest correlations for the relationship between locomotor- and balance skills, and weakest for balance skills in relation to object control skills.

Multivariate pattern analyses

The association patterns for the PA spectrum were similar for the locomotor skill (R^2 = 9.7% for the vertical axis; 11.4% for all axes) and object control skill domains (R^2 = 3.9% for the vertical axis; 3.5% for all axes). For balance skills, a multivariate association pattern did not exist (result not shown as the model was not statistically significant). Figure 1 illustrates the association pattern with locomotor skills for the PA intensity spectrum of the vertical (Robinson et al., 2015), the antero-posterior (Holfelder & Schott, 2014), and medio-lateral (Logan et al., 2015) axis, respectively. PA intensity intervals between 5000 and 8000 cpm were most strongly related to locomotor- and object control skills, whereas associations for lower and higher intensities gradually weakened. Time spent in 0–99 and 100–249 cpm was negatively associated with locomotor- and

Table 2. Correlations (Pearsons r) for physical activity (PA) intensities with fundamental motor skills (FMS).

	Fundamental motor skills		
PA-variables	Locomotion	Object control	Balance
TPA (cpm)	0.23**	0.16**	0.04
SED (min/day)	−0.21**	−0.14**	−0.001
LPA (min/day)	0.05	0.03	−0.01
MPA (min/day)	0.20**	0.11**	0.03
VPA (min/day)	0.26**	0.18**	0.04
MVPA (min/day)	0.26**	0.16**	0.04

TPA: Total physical activity; SED: Sedentary time; LPA: Light physical activity; MPA: Moderate physical activity; VPA: Vigorous physical activity; MVPA: Moderate-to-vigorous physical activity. Models are adjusted for age, sex, parental socioeconomic status, season, test person FMS assessment, accelerometer wear time, BMI, and preschool. *Significant associations at $p < 0.05$, **significant associations at $p < 0.001$.

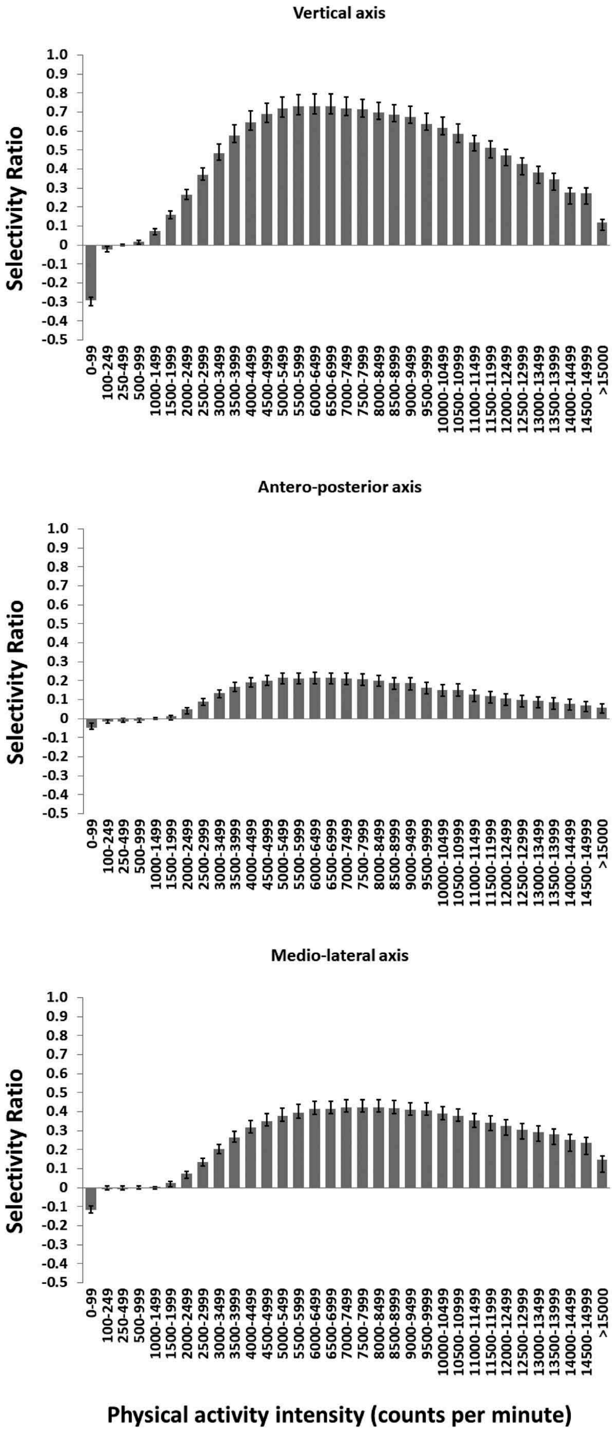

Figure 1. The multivariate physical activity signature associated with fundamental motor skills (FMS) in the locomotor domain displayed as a selectivity ratio (SR) plot. The model (PLS regression) is adjusted for age, sex, body mass index, socioeconomic status, test person FMS testing, accelerometer wear time, and preschool. Locomotor skills: R^2 = 9.7% for the vertical axis only; 11.4% for all 3 axes combined. The SR is calculated as the ratio of explained to residual variance on the predictive (target projected) component. A positive bar implies that increased PA are associated with better locomotor skills.

object control skills. The association patterns were similar for boys and girls, and across age (median split, 50% youngest vs. 50% oldest) (r = 0.82–0.98). The association patterns were strongest for the vertical axis for all outcomes, but otherwise fundamentally similar across the three axes.

Discussion

We investigated the PA intensity signature associated with FMS using multivariate pattern analyses. This novel approach shows how the whole intensity spectrum of PA associates to FMS in preschool children. The intensity profile associated with FMS was characterised by vigorous intensities (Evenson et al., 2008; Freedson, Pober, & Janz, 2005), while weaker associations were found with MPA, LPA (both positive), and SED (negative). The strongest associations were found for FMS within the locomotor domain, whereas the associations for object control skills were somewhat weaker. No association pattern was found for skills within the balance domain.

As reported elsewhere for the current sample (Nilsen, Anderssen, Ylvisaaker, Johannessen, & Aadland, 2019), and in line with previous evidence (Tonge, Jones, & Okely, 2016), our results show that boys were more physically active and less sedentary compared to girls, and that PA increased by age. Regarding FMS, our findings are consistent with evidence showing that FMS are strongly related to age, and that boys perform better on object control skills, whereas girls perform better on balance skills (Barnett et al., 2016). In our sample, girls also scored higher on locomotor skills compared to boys, which is in line with the results of Cliff et al. (Cliff, Okely, Smith, & McKeen, 2009).

Our findings from the multivariate analysis (Figure 1) suggest that accumulated time in 5000–8000 cpm are strongest related to skills within the locomotor- and object control domain. Although weaker associations were found for intensities in the light (≈ 100–2500 cpm) and moderate (≈ 2500–4000 cpm) range (Evenson et al., 2008), the association pattern was clearly dominated by intensities in the upper vigorous range (e.g. activities involving running, hopping, chasing etc.). Thus, this intensity-range could be an important target for future studies related to FMS, if not using the whole intensity spectrum. Our results further supports the use of Evenson et al. cut points for VPA (≥ 4000 cpm) when studying PA related to FMS in preschoolers (Evenson et al., 2008).

The results from the multivariate pattern analyses correspond well with those from the bivariate analysis presented herein, and with most previous findings, however more nuanced. MVPA and VPA are commonly associated with FMS (Barnett et al., 2016; Barnett, Morgan, Van Beurden, Ball, & Lubans, 2011; Burgi et al., 2011; Fisher et al., 2005; Foweather et al., 2015; Iivonen et al., 2013; Lopes et al., 2019; Lubans, Morgan, Cliff, Barnett, & Okely, 2010; Williams et al., 2008), whereas the few studies that have investigated LPA show inconsistent results. Some studies report no relationship between LPA and FMS (Fisher et al., 2005; Lopes et al., 2019; Williams et al., 2008; Wrotniak et al., 2006), while others have shown positive associations (Foweather et al., 2015; Iivonen et al., 2013). In the present detailed and integrated analyses we found that PA within the typical LPA range were associated with FMS (locomoor- and object control skills); however the relationships were weaker than for higher intensities. Few studies have investigated the association between SED and FMS; however, some studies have indicated that lower SED is associated with better FMS (Lopes et al., 2012; Williams et al., 2008; Wrotniak et al., 2006). We hypothesised a negative relationship between SED and FMS, as previously shown by Lopes et al. (Lopes et al., 2012). As displacing SED inevitably means introducing PA (van der Ploeg & Hillsdon, 2017), we would expect an opposite trend with FMS for SED compared to PA, which was confirmed for both domains where an association was evident (locomotor- and object control skills).

We find it plausible that different PA intensities may have different associations to different domains of FMS, as they may represent different types of activities (Barnett et al., 2016). Skills within the locomotor domain are typically needed during activities that requires high intensity (i.e., running, jumping etc.), and high participation in these activities would likely be associated with better locomotor skills. Furthermore, while locomotor skills involve moving the body through space, such skills are often involved in activities that also involves object control (e.g., ball games). Therefore, it is natural that these types of skills are highly associated with VPA, while the mechanisms behind the development of balance skills might have other characteristics. However, we find is somewhat unexpected that PA was not associated with balance skills.

The weaker associations found for the relationship between PA and object control skills than for locomotor skills could possibly be explained by the accelerometer placement (hip), which has limitations with regard to capturing for example upper body movement like throwing or catching a ball (Evenson et al., 2008). Thus, such movements are probably not captured optimally and the intensity during the execution of object control activities are likely underestimated when measured with an accelerometer (Sacko, McIver, Brian, & Stodden, 2018). This limitation might lead to somewhat weaker associations for object control skills than locomotor skills.

The majority of studies using accelerometry in preschool children apply the vertical axis only (Kim, Lee, Peters, Gaesser, & Welk, 2014). However, it has been hypothesised that triaxial accelerometry may better capture free-living daily activities (Eston, Rowlands, & Ingledew, 1998; Plasqui, Joosen, Kester, Goris, & Westerterp, 2005; Santos-Lozano et al., 2013; Tanaka, Tanaka, Kawahara, & Midorikawa, 2007; Westerterp, 2009), which would imply application of triaxial data could reveal stronger associations to FMS. However, our findings show that uniaxial and triaxial accelerometry provided similar information regarding FMS. Thus, although we agree that triaxial accelerometry may have potential to capture important aspects of children's PA, our findings do not support this hypothesis with regard to FMS skills in preschoolers.

Perspectives

Focusing on PA promotion in preschoolers is important as PA behaviours established during early childhood may track into later childhood (Janz, Burns, & Levy, 2005) and adolescence (Kristensen et al., 2008). Moreover, the early childhood years is a critical time for the development of FMS, and a certain level of skill competence is necessary to participate in various types of PA. Although we acknowledge the cross-sectional nature of the present study and the limitations it holds for drawing causal inferences, we argue that the results presented are important for informing preschoolers' guidelines for PA. Our results suggest that preschoolers should spend time in vigorous intensity to improve their FMS, and/or that an adequate level of FMS is important for engagement in VPA. Longitudinal and experimental studies are, however, needed to determine the direction and predictive value of the relationship between PA and FMS in preschoolers.

Strengths and limitations

In addition to the large study sample and the high compliance to the protocol, the simultaneous modelling of the whole intensity spectrum of PA, without use of pre-defined accelerometer cut points, are major strengths of the present study.

Multivariate pattern analyses is widely applied in pharmaceutical (Rajalahti & Kvalheim, 2011) and metabolomics studies (Madsen, Lundstedt, & Trygg, 2010), and in treatment research and diagnosis of diseases (Rajalahti et al., 2010). This analytic approach can handle multicollinearity among accelerometer variables, and thus allow for modelling associations across the whole PA intensity spectrum in a mutual model. As previously called for (Barnett et al., 2016; Poitras et al., 2016; van der Ploeg & Hillsdon, 2017), by using the whole intensity spectrum, we provide a much more nuanced picture of the associations between PA and FMS.

A general limitation with accelerometer data is that they do not provide a perfect measure of true SED time or very high PA intensities, nor a correct classification of intensity in certain activities (e.g., cycling, swimming) (Cain et al., 2013). Our findings should therefore be considered with limited classification accuracy of PA intensity, and posture allocation, taken into account. Another important issue in accelerometer data reduction and scoring is the choice of epoch length. Because children's natural PA pattern is rather sporadic, with bouts of PA generally lasting <10 seconds (Aadland, Andersen, Anderssen, Resaland, & Kvalheim, 2018; Rowlands, Pilgrim, & Eston, 2008; Sanders, Cliff, & Lonsdale, 2014; Vale, Santos, Silva, Soares-Miranda, & Mota, 2009), it has been concluded that studies should apply shorter epochs than the traditional 60-second epoch duration to capture PA correctly (Cain et al., 2013). Summation of PA over longer epoch periods leads to loss of time spent in the lower and higher end of the intensity spectrum (i.e.; overestimation of LPA, and underestimation of SED and VPA) (Aadland et al., 2018; Banda et al., 2016; Nettlefold et al., 2016; Sanders et al., 2014; Vale et al., 2009). Therefore, we used 1-second epochs to avoid loss of information and misclassification of PA intensity in the present study.

It is well known that ActiGraph counts levels-off for high-intensity activities, such as running (Brage, Wedderkopp, Franks, Andersen, & Froberg, 2003; John, Miller, Kozey-Keadle, Caldwell, & Freedson, 2012), and thus, underestimates high intensity activities. The accelerometer has a frequency filter (0.25–2.5 Hz) (John & Freedson, 2012), which reduces the signal of high intensities to avoid noise, with the consequence of reducing counts in the physiological range of human movement, possibly attenuating the relationship between high intensity PA and FMS. Thus, the inverted-U pattern for the association between PA and FMS illustrated in Figure 1, showing attenuating associations ≥8000 cpm, is likely to be a spurious finding.

There is no established "gold standard" of assessment of FMS in children (Logan, Robinson, & Getchell, 2011). In the present study, we used a test battery inspired by the TGMD-3 (Ulrich, 2019), as prior editions of the TGMD is widely used in preschoolers (Hardy, King, Farrell, Macniven, & Howlett, 2010; Logan et al., 2011). However, the TGMD-3 was developed in the US and contains particular movement tasks that are less culturally relevant in Nordic countries (e.g., the baseball strike and bouncing ball). Furthermore, the test battery does not contain balance tasks. To be able to measure FMS in a large study sample and at the same time cover the three main domains of FMS (Gallahue & Cleland-Donnelly, 2003; Sun et al., 2010), we choose to modify and extend the TGMD-3 by reducing the total number of items and by introducing balance skills (Sun et al., 2010).

We also chose a scoring procedure that is independent of the number of criteria of each skill (mean score vs. the original sum score). Thus, our results are not comparable with other studies using the TGMD-3, nor are we able to determine whether the skill level in our sample of children is considered high or low, which is a limitation for comparison across studies and possibly for practical implications. The purpose of this study was, however, to determine the PA intensity pattern that was associated with FMS in preschool aged children, not to identify children with high or low motor skill levels or developmental disorders. Moreover, reporting of sum scores according to the original procedures might be misleading in this case – as the domain scores would be lower compared to completing the whole test battery (TGMD-3: 6 vs. 13 items). Nevertheless, both sum- and mean scores provide similar information (Pearsons' $r = 0.98–0.99$ for a sum score and mean score across the domains).

The average parental educational level among children included in the analyses was higher than among the excluded children, and almost all the participating children were born in Norway. Furthermore, our sample consisted of healthy children without known disabilities that could affect PA levels or FMS performance. This means that caution should be exercised in generalising the results to populations comprising ethnic minorities, children with developmental disorders, or populations with lower SES.

Conclusion

This study demonstrates innovation by investigating the association patterns of PA intensities with FMS in young children using multivariate pattern analysis. Our main conclusions were that the strongest positive associations with FMS were found for VPA, whereas other intensities demonstrated weaker associations. Although we cannot draw conclusions with regard to causality, our findings suggest that future studies and practice should focus on VPA to improve locomotor- and object control skills, and likewise; focus on improving locomotor- and object control skills to increase VPA, in preschool aged children.

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Availability of data and material

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Authors contributions

EAA designed and obtained funding for the study. EAA, SAA and AKON were involved in the development of the research questions. AKON, EY, and KJ performed the data collection. AKON and EAA analyzed the data. AKON drafted the manuscript. All authors contributed to the interpretation of data and were involved in critical revisions of the manuscript. All authors read and approved the final version.

Disclosure statement

No potential conflict of interest was reported by the authors.

Ethics approval and consent to participate

Parents of all participating children received oral and written study information and provided written consent prior to testing. Children were provided with an explanation of the measurements according to their level of understanding. The Norwegian Centre for Research Data (NSD) approved the study (reference number: 39061).

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STUDY IV

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Bi-directional prospective associations between objectively measured physical activity and fundamental motor skills in children: a two-year follow-up

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Abstract

Background: The direction of the longitudinal relationship between physical activity (PA) and fundamental motor skills (FMS) remains unclear. We evaluated the bi-directional, prospective relationships between intensity-specific physical activity (PA) and domain-specific fundamental motor skills (FMS) over 2 years in children attending preschool at baseline.

Methods: A sample of 230 children (mean age at baseline 4.7 yr, 52% boys) from the 'Sogn og Fjordane Preschool Physical Activity Study' was measured 2 years apart. PA was assessed using ActiGraph accelerometers (GT3X+). FMS were evaluated by a test battery guided by the 'Test of Gross Motor Development 3' and the 'Preschooler Gross Motor Quality Scale'. PA outcomes were total PA (TPA [counts per minute]) and intensity specific PA and sedentary behaviour (SED) (min/day). FMS outcomes were locomotor, object control, and balance skills. Linear mixed model adjusting for potential co-variates was used to evaluate the bi-directional prospective associations between these variables, including the moderating effect of sex and age.

Results: Baseline total PA, moderate-to-vigorous PA (MVPA), and vigorous PA predicted higher locomotor, object control, and balance skills at follow-up (standardized regression coefficient (β): 0.17 to 0.26, $p = 0.002–0.017$). Baseline SED predicted lower locomotor skills at follow-up (β: − 0.27, $p = 0.012$). Baseline light PA did not predict FMS at follow-up. Baseline FMS were not associated with PA or SED at follow-up.

Conclusions: MVPA was positively associated with development of FMS in young children. In contrast, FMS were not related to future PA levels. Our results suggest promotion of MVPA is important for FMS development in young children.

Keywords: Longitudinal association, Health behaviour, Motor competence, Motor development, Movement, Accelerometer, Reciprocal relationship, Preschool, Physical activity measurement

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Background

Health related behaviours, such as physical activity (PA) and sedentary behaviour (SED), are typically established during early childhood, and evidence suggests that these behaviours track over time [1]. As PA levels are known to decrease by age in school-aged children and adolescents [2], the preschool years is a critical period to ensure sufficient levels of PA [3] for health and normal development [4–6]. Therefore, it is recommended that children engage in ≥ 60 min of moderate to vigorous PA (MVPA) daily [7]. However, many children fail to meet these guidelines [8–10].

In order to establish sufficient levels of PA during early childhood, research should aim to identify factors influencing PA behaviours [11]. Fundamental motor skills (FMS), including locomotor (moving the body through space, e.g., run, hop, jump), object control (manipulation and projecting of objects, e.g., catch or throw a ball), and balance skills (e.g., dynamic and static balance) [12], has been highlighted as important determinants of PA and other health related outcomes [13]. FMS' are considered the 'building blocks' of more advanced, complex movements [14]. Children develop their FMS through engagement in PA [15], as increased PA provides more opportunities to promote neuromotor development, which in turn promotes FMS development [16–18]. At the same time, learning to move is a necessary skill underlying PA [18]. Proficiency in FMS is considered vital to achieve and maintain sufficient levels of PA [19, 20] and to develop more complex motor skills [13, 18]. Yet, many children have sub-optimal FMS levels [21–23].

Based on the conceptual model introduced by Stodden et al. in 2008 [18], the relationship between FMS and PA is likely to be bi-directional. In addition, the relationship may differ at different stages of a child's development. While Stodden et al. hypothesised engagement in PA to be important for the development of FMS during the early years, FMS levels were hypothesised to become more important for PA participation as the child gets older (and becomes more motor competent) [18]. Numerous studies have examined the cross-sectional relationship between FMS and PA in children, supporting a low to moderate, positive association ($r < 0.50$) between FMS and levels of total PA (TPA), light PA (LPA), and MVPA [13, 19]. However, few longitudinal studies using objective measures of PA exist, and thus, the direction of the associations remains unclear.

A recent study by Schmutz et al. showed that FMS predicted higher accelerometer derived TPA and MVPA over a period of 12 months in children aged 2 to 6 years at baseline ($N = 555$) [24]. In addition, Venetsanou and Kambas [25] explored the longitudinal associations between FMS in preschoolers and PA measured with pedometers 10 years later ($N = 106$), and found that FMS during the preschool years predicted higher PA levels in adolescence. However, this study did not consider intensity-specific PA [25]. Importantly, though, these studies did not adjust for baseline PA levels, limiting their conclusions with regard to the direction of the association. Lopes et al., on the other hand, performed a longitudinal analysis showing that FMS positively predicted change in moderate PA (MPA), MVPA, and TPA in adolescents ($N = 103$) at 2-year follow-up [26]. Similarly, Larsen et al. found that motor performance positively predicted change in MVPA at 3-yr follow-up in their sample of 6–12 year old Danish children ($N = 673$) [27].

Since previous longitudinal studies primarily have focused on FMS as a determinant of PA, less is known about the predictive role of PA on FMS development. Although Barnett et al. found that MVPA at age 3.5 years was positively associated with locomotor skills at age 5 in a sample of preschoolers ($n = 127$) [28], their results are limited by the lack of adjustment for baseline levels of the outcome.

Only one previous study have investigated the bi-directional, prospective relationship between objectively measured PA and FMS in childhood. Lima et al. found that vigorous PA (VPA) and FMS presented a direct bi-directional, positive, prospective association over a 7-year follow-up of 513 children aged 6–13 years in the Copenhagen School Child Intervention Study (CoSCIS) [29]. Thus, their results correspond with the proposed model of Stodden et al. [18]. However, the authors urge future studies to investigate whether the strength of the associations between PA and FMS change during childhood [29]. In addition, Lima et al. only tested FMS within the locomotor domain; thus, more longitudinal research including other aspects of FMS (e.g., object control and balance skills) is needed.

To the best of our knowledge, no previous study has investigated the prospective, bi-directional relationship between PA and FMS in preschoolers using objective measures of PA. Considering the benefits of both PA and FMS for future health, an improved understanding of these variables' interrelationships is an important public health focus in young children. Therefore, the aim of this study was to examine the prospective, bi-directional relationship between intensity-specific PA and domain-specific FMS in preschool-aged children over a period of 2 years.

Methods

Study design and recruitment of participants

The present study is a longitudinal analysis based on data from the 'Sogn og Fjordane Preschool Physical Activity Study' (PRESPAS) [30, 31]. PRESPAS was conducted in Sogn og Fjordane county, a rural area in western Norway, between September 2015 and June 2016 and involved in total 1308 children aged 2.7–6.5 years (born in 2010–2012) from 68 preschools (response rate 68%). The present study is based on a subsample of 376 invited children from 20 preschools, providing data at baseline (2015–2016) and at a two-year follow-up (September–October 2017).

Parents of all participating children received oral and written information about the study and provided written consent prior to testing. Preschools (at baseline and follow-up) and schools (at follow-up) received information about the study and agreed to participate in the study. We explained the procedures according to the children's level of understanding. The Norwegian Centre for Research Data (NSD) approved the study (reference numbers: 39061 and 48016).

Procedures

Physical activity measurement

PA was measured using the ActiGraph GT3X+ accelerometer (ActiGraph, LLC, Pensacola, Florida, USA) [32]. Children wore an elastic belt with the accelerometer on the right hip, and were instructed to wear the monitor at all times for 14 consecutive days, except during water-based activities and while sleeping (at night). Accelerometers were initialized with a sampling rate of 30 Hz and analysed using 1-s epochs using the KineSoft software (KineSoft version 3.3.80, Loughborough, UK). Periods of ≥20 min of zero counts were defined as non-wear time [33]. Our criterion for a valid day was ≥480 min of wear time accumulated between 06:00 and 24:00 h. We included all children who provided ≥4 days of valid PA data in the analysis. Children were asked to perform three PA-registration periods during the baseline year (autumn 2015, winter, and spring/summer 2016), and one PA-measurement at follow-up (autumn 2017), providing up to 6 weeks of PA data at baseline, and 2 weeks at follow-up. An average of the three PA measurements is used at baseline (in case of one missing observation, a mean of the two remaining PA registrations were used). PA outcomes were TPA (counts per minute [cpm]) and intensity-specific PA, reported as SED (≤ 100 cpm), LPA (LPA) (101–2295 cpm), MPA (2296–4011), VPA (≥4012 cpm), and MVPA (min/day) (≥2296 cpm), as proposed by Evenson et al. [34].

Fundamental motor skills

To measure FMS, we developed a test battery guided by the 'Test of Gross Motor Development 3' (TGMD-3) [35, 36]. TGMD-3 is designed for children aged 3–10 years, and originally based on observation of children's movements across 13 tasks within the two domains: locomotion (run, skip, slide, gallop, hop, and horizontal jump) and ball/object control (hereafter referred to as 'object control') (overhand throw, underhand throw, catch, dribble, kick, one-hand strike, and two-hand strike). We modified this test battery to reduce the participant and researcher burden, and at the same time cover the three main domains of FMS by including balance skills [37, 38]. We therefore included six movement tasks from the TGMD-3 battery (run, horizontal jump, hop, catch, overhand throw, and kick), in addition to three movement tasks within the balance domain (single leg standing, walking line forward, and walking line backward) from the 'Preschooler Gross Motor Quality Scale' (PGMQ) proposed by Sun et al. [37], in our assessment of FMS. The specific skills were selected based on their relevance (e.g., some of the movement tasks in the TGMD-3, like the baseball strike and dribble, are less common and therefore less relevant in assessments of Norwegian children), and variety (e.g., including object control skills related to both hands and feet, and adding both static and dynamic balance tests) in terms of broadly capturing children's skills within the three FMS domains.

FMS were measured one time at baseline (autumn 2015 - winter 2016), and one time at follow-up (autumn 2017). Children were evaluated in small groups (4–5 children) during preschool/school hours, and were asked to perform the nine movement tasks in a safe environment with enough space to move freely. Each child performed each skill twice and skills were completed in a standardised order, taking approximately 25–30 min per group. The test teams consisted of one instructor who provided a verbal description and demonstration of the required skill, while a separate rater observed and scored the performance. We administered the FMS measurements according to TGMD-3 (locomotor and object control skills) and PGMQ (balance skills) protocols. Children were scored quantitatively based on a qualitative evaluation of whether the child did or did not demonstrate specific process criteria for each skill/item based on the original scoring procedures for TGMD-3 (marked as either absent: "0" or present: "1") [35–37]. The children had two trials per task, and the score from trial 1 and 2 were summed, thus - providing a score of 0 to 2 points per criteria. The criteria scores were summed for each item and each domain, providing domain scores of maximum 24 points for locomotor and balance skills (4 criteria per item, 3 items), and maximum 20 points for object control skills (3 criteria for 'catch' and 'kick', 4 criteria for 'overhand throw'). In total, six raters took part in the assessment of FMS. Prior to the data collection, all raters were thoroughly trained in how to instruct and score children in the different movement tasks. Inter-rater reliability (ICC) (based on in-field concurrent scoring of 26 children) was 0.90 for the locomotor items, 0.74 for the object control items, and 0.86 for the balance items.

Anthropometrics

We assessed children's body weight and height during preschool hours. Body weight was measured to the nearest 0.1 kg using an electronic scale (Seca 899, SECA GmbH, Hamburg, Germany), and height was measured to the nearest 0.1 cm with a portable stadiometer (Seca 217, SECA GmbH, Hamburg, Germany). Body weight and height were measured at the same time as PA during baseline and follow-up (i.e., three times during the baseline year, and one time at follow-up). Body mass index (BMI, kg/m^2) was calculated and used as a continuous variable in the association analyses (an average of the three baseline measurements is used). Children were additionally classified as normal weight, overweight, or obese based on criteria proposed by Cole et al. [39] for descriptive purposes.

Other covariates

Children's sex, age, and parental socioeconomic status (SES, based on the highest education level and the highest yearly income of mother or father) were assessed using a questionnaire completed by each child's mother and/or father at baseline. The included co-variates were chosen based on known influence on PA and FMS outcomes [2, 40, 41].

Statistical analysis

Children's characteristics, FMS, PA, and SED were reported as frequencies, means, and standard deviations (SD), except for the number of valid days of accelerometer data, which was reported as the median. We tested for differences in characteristics between children providing valid PA and FMS data at both time points and those who did not using a two-level linear mixed model for continuous outcomes and a generalized estimating equation using an exchangeable correlation structure for categorical outcomes, to account for clustering among preschools. We used Pearson's correlations, change scores, and paired sample t-test to describe the differences in anthropometrics, FMS, and PA and SED between baseline and follow-up. Age-groups were based on median split (50% youngest, 50% oldest) for descriptive purposes in Additional file 3: Figure S1, and age-categories (≤ 3.49 years = 3; 3.50–4.49 years = 4; 4.50–5.49 years =5; ≥ 5.50 years = 6) for reporting of age-specific estimates in Fig. 1 and Additional file 1: Table S1 and Additional file 2: Table S2. For Additional file 6: Table S5, age-equivalents were categorized according to TGMD-3 (i.e., 3-month intervals) [36]. The cross-sectional analyses of the relationship between PA and FMS at baseline and at follow-up (Additional file 5: Table S3 and Additional file 4: Table S4) were performed using a linear regression model adjusted for potential co-variates (same as reported below).

The prospective association analyses were performed using a two-level linear mixed model including clustering of observations within individuals. The outcome at follow-up (PA or FMS) was the dependent variable in all models, while the independent variables were PA or FMS at baseline and the following covariates: sex, baseline age, baseline BMI, parental education and income level, accelerometer wear time at both time points (when PA was the outcome) and the person scoring FMS at both time points (when FMS was the outcome). All prospective analyses were adjusted for baseline value of the outcome. The analyses was repeated using different PA variables (LPA, MPA, VPA, MVPA, TPA), SED, as well as FMS (locomotor, object control, and balance skills) as predictors and outcomes. We did sensitivity analysis including random intercepts for clusters (preschool or school) at follow-up (i.e., a three-level model). However, because results from the three-level and two-level models were similar, we only reported results from the two-level models.

Furthermore, we tested for interactions by sex (baseline exposure (PA or FMS) × sex) and age (baseline exposure (PA or FMS) × baseline age) by adding these interaction terms to the models described above. In all models, FMS, SED, and PA variables were analysed one by one to avoid multi-collinearity.

For reporting of prospective associations, all FMS and PA variables were standardized to z-scores for ease of interpretation, thus, the regression coefficients are given in SD units. All analyses were performed using IBM SPSS v. 24 (IBM SPSS Statistics for Windows, Armonk, NY; IBM Corp., USA). $p < 0.05$ indicated statistically significant findings.

Results

Descriptives

Children's characteristics are presented in Table 1. All of the 376 invited children participated in at least one measurement of PA at baseline, whereas 238 (63%) and 257 (68%) children had valid FMS and PA data, respectively, at both baseline and follow-up ($n = 292$ children (78%) had valid PA data at all three time points during the baseline measurements). In total, 230 (61%) children provided valid PA and FMS data at both baseline and follow-up and were included in the analyses. Compared to the included children, excluded children ($n = 146$) had parents with lower education and income levels ($p < 0.05$), but were otherwise similar to the study sample.

Development in PA and FMS

The children had a median of 12 valid days of PA at both baseline and follow-up. Both PA and FMS levels changed significantly over 2 years (Table 1). Results show greater increase in TPA, MPA, VPA, and MVPA

Table 1 Children's characteristics at baseline and follow-up

	n	Baseline 2015/2016	Follow-up 2017	Pearson's correlations	Change	*P* values [d]
Age (years)	*376*	4.7 (0.9)	6.4 (0.9)	–	–	–
Boys (%)	*376*	52%	–	–	–	–
Anthropometrics	*249*					
Body height (cm)		109 (7.8)	121 (7.6)	0.962, $p < 0.001$	12.0 (2.1)	$p < 0.001$
Body mass (kg)		19.0 (3.2)	23.6 (4.3)	0.912, $p < 0.001$	4.6 (1.9)	$p < 0.001$
BMI (kg x m^2)		16.1 (1.3)	16.0 (1.7)	0.790, $p < 0.001$	−0.1 (1.0)	$p = 0.328$
Weight status[a] (%)						
Normal weight		84%	85%	–	–	–
Overweight		15%	12%	–	–	–
Obese		1%	3%	–	–	–
Parental education level[b]	*326*					
Upper secondary school (%)		16%	–	–	–	–
University < 4 years (%)		29%	–	–	–	–
University $\underline{>}$ 4 years (%)		55%	–	–	–	–
Fundamental motor skills[c]	*238*					
Locomotor skills		15.1 (4.4)	16.3 (4.0)	0.439, $p < 0.001$	1.2 (4.5)	$p < 0.001$
Object control skills		10.4 (2.9)	16.8 (2.9)	0.503, $p < 0.001$	6.4 (2.9)	$p < 0.001$
Balance skills		16.5 (4.9)	21.1 (3.4)	0.557, $p < 0.001$	4.6 (4.2)	$p < 0.001$
Physical activity	*257*					
Wear time (min/day)		692 (43)	724 (54)	0.495, $p < 0.001$	32 (50)	$p < 0.001$
SED (min/day)		474 (39)	503 (47)	0.616, $p < 0.001$	29 (38)	$p < 0.001$
TPA ([cpm])		722 (147)	741 (165)	0.522, $p < 0.001$	19 (154)	$p = 0.042$
LPA (min/day)		144 (16)	139 (18)	0.635, $p < 0.001$	−5 (15)	$p < 0.001$
MPA (min/day)		36 (6)	39 (8)	0.601, $p < 0.001$	3 (6)	$p < 0.001$
VPA (min/day)		34 (9)	39 (10)	0.580, $p < 0.001$	5 (9)	$p < 0.001$
MVPA (min/day)		70 (14)	77 (16)	0.610, $p < 0.001$	7 (14)	$p < 0.001$

All values are reported as means (standard deviations) unless stated otherwise. [a]Weight status according to Cole et al., 2000. [b]Parental education and income level: *highest level of mother or father used.* [c] Score range locomotor and balance skills: 0–24; object control skills: 0–20. [d] The change from baseline to follow-up was analysed with the use of a paired-sample T-test. *P*-values is statistic significant to the level of $p < 0.05$. *BMI* Body mass index, *SED* Sedentary time, *TPA* Total physical activity, *cpm* Counts per minute, *LPA* Light physical activity, *MPA* Moderate physical activity, *VPA* Vigorous physical activity, *MVPA* Moderate-to-vigorous physical activity

from baseline to follow-up in boys compared to girls (Additional file 1: Table S1; Fig. 1 for MVPA). For SED, the trends were opposite (Additional file 1: Table S1). The development in PA was further strongly associated with age, with the younger children having a stronger, positive development in TPA, MPA, VPA, and MVPA (Additional file 1: Table S1 and Additional file 3: Figure S1; and Fig. 1 for MVPA), and a relatively smaller, positive development in SED, and smaller, negative development in LPA, when compared to the older children (Additional file 1: Table S1; Additional file 3: Figure S1).

Concerning FMS, skills within all three domains improved over 2 years (Table 1). There was no difference in FMS development between boys and girls; however, increased age at baseline were associated with greater development in object control skills (Additional file 2: Table S2).

Cross-sectional relationships between PA and FMS

There were significant, positive associations between TPA, MPA, VPA, and MVPA and locomotor and object control skills at both time points (Additional file 5: Table S3 and Additional file 4: Table S4). SED was negatively associated with locomotor and object control skills at baseline, and with object control skills at follow-up. Balance skills were not associated with PA or SED, and LPA was not associated with FMS. Overall, the strength of the associations were similar at baseline and follow-up.

Prospective, bi-directional relationships between PA and FMS

TPA, VPA, and MVPA at baseline predicted higher locomotor, object control, and balance skills at follow-up ($p < 0.017$) (Table 2). MPA predicted higher locomotor

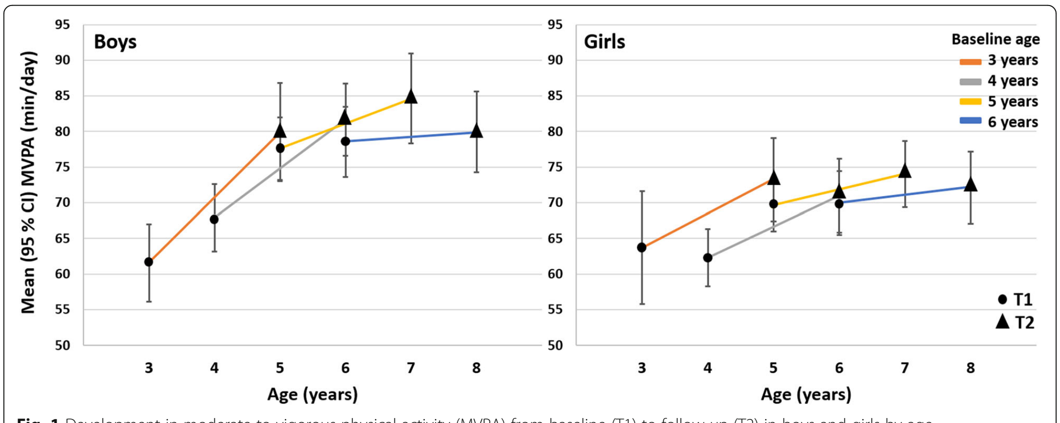

Fig. 1 Development in moderate-to-vigorous physical activity (MVPA) from baseline (T1) to follow-up (T2) in boys and girls by age

and balance skills at follow-up ($p < 0.032$). SED predicted lower locomotor skills ($p = 0.012$). LPA did not predict FMS at follow-up. We found no interactions with sex or age for the prospective relationship between PA (any intensity) or SED at baseline and FMS at follow-up ($p =$ 0.122–0.995).

When FMS were modelled as the exposure and PA as the outcome, there was no prospective associations (Table 3). Furthermore, we found no interactions with sex or age for the prospective relationship between FMS at baseline and PA (any intensity) or SED at follow-up ($p =$ 0.055–0.957).

Discussion

This study extends the current evidence regarding the relationship between PA and FMS by examining the prospective, bi-directional associations between intensity-specific PA and domain-specific FMS in young children. While baseline PA of at least moderate intensity predicted higher FMS at follow-up, baseline FMS were not predictive of future PA levels.

We found that children who engaged in more MVPA and VPA during the preschool years performed better on FMS's (all domains) 2 years later. These findings are consistent with the few previous studies that have examined prospective associations between PA and FMS in children [28, 29]. Similar to Lima et al., we found that associations were stronger for VPA than MPA [29]. Furthermore, LPA at baseline did not predict any FMS variable at follow-up. There was also a negative, prospective association between baseline SED and locomotor skills at follow-up. Based on our results, for each additional SD in MVPA (≈15 min), the locomotor skill score increased by 0.26 SD (≈15% increase). In comparison, Lima et al. found that locomotor skills increased by 0.14 SD for each additional SD in MVPA [29]. Because small improvements in FMS may enhance physically active play opportunities, and because others find a bi-directional relationship between PA and FMS in older children [29], we regard this increase meaningful for children's development. Therefore, in line with Barnett et al. [28], our findings shows the importance of MVPA during the preschool years for FMS development.

Contrary to the findings above, we did not observe any prospective associations between FMS at baseline and PA at follow-up.

In line with the theory by Stodden et al., one would expect that motor competent children experience greater success and enjoyment during physically active play, and therefore would participate more in PA [18]. Thus, the lack of prospective associations between FMS (predictor) and MVPA (outcome) contrasts previous findings [24–27, 29]. A direct comparison of our results with previous studies is, however, difficult due to differences in follow-up duration, age of participants and different assessment methods for FMS.

We hypothesise that the null-findings regarding prospective relationships between FMS (predictor) and PA (outcome) could be explained by the great development in FMS that happens during the preschool and early school years [38]. Since FMS improves substantially over 2 years in young children [24, 28, 40], it may be reasonable to believe that the current motor skill level would be more strongly related to MVPA than the previous skill level. Our results from the cross-sectional analysis, showing comparable associations between PA and FMS at both baseline and follow-up, may support this theory, although the direction of the association cannot be determined from cross-sectional analyses. Nevertheless, our results are in contrast to those of Barnett et al., who

Table 2 Prospective associations between physical activity at baseline (exposure) and fundamental motor skills at follow-up (outcome) (*n* = 217)

		Outcome at follow-up		
		Locomotor skills	Object control skills	Balance skills
Exposure at baseline	TPA ([cpm])	0.23 (0.07, 0.39) ***p* = 0.006**	0.22 (0.07, 0.36) ***p* = 0.004**	0.17 (0.03, 0.30) ***p* = 0.014**
	SED	−0.27 (−0.47, −0.06) ***p* = 0.012**	−0.19 (−0.38, −0.01) *p* = 0.061	−0.14 (−0.32, 0.05) *p* = 0.155
	LPA	0.10 (−0.04, 0.24) *p* = 0.154	0.09 (− 0.04, 0.21) *p* = 0.192	0.09 (− 0.04, 0.21) *p* = 0.164
	MPA	0.22 (0.07, 0.37) ***p* = 0.005**	0.13 (−0.01, 0.27) *p* = 0.077	0.15 (0.03, 0.28) ***p* = 0.032**
	VPA	0.25 (0.08, 0.41) ***p* = 0.003**	0.19 (0.05, 0.34) ***p* = 0.010**	0.20 (0.06, 0.33) ***p* = 0.005**
	MVPA	0.26 (0.09, 0.42) ***p* = 0.002**	0.18 (0.03, 0.33) ***p* = 0.017**	0.19 (0.05, 0.33) ***p* = 0.007**

All values are standardized β coefficients (95% CI), analysed with a linear mixed model. The models are adjusted for sex, baseline age, baseline body mass index, parental education- and income level, FMS assessor at baseline and at follow-up, baseline accelerometer wear time, and baseline value of the outcome. *TPA* Total physical activity, *cpm* Counts per minute, *SED* Sedentary behaviour, *LPA* Light physical activity, *MPA* Moderate physical activity, *VPA* Vigorous physical activity, *MVPA* Moderate-to-vigorous physical activity, *FMS* Fundamental motor skills. *P*-value in bold is statistic significant to the level of $P < 0.05$

found no cross-sectional relationship between MVPA and FMS in children at age five [28]. Barnett et al. did, however, find a prospective association between MVPA at age 3.5 and locomotor skills at age 5, which is consistent with our findings. Although Barnett et al., did not investigate the bi-directional relationship between these variables, our studies combined suggest that PA is more important for FMS development than FMS is for PA development in normally developing preschoolers.

Previous research has shown that a certain level of FMS is important for various health and learning outcomes [13, 42], and for participation in PA [24, 29, 40]. However, our findings support the hypothesis of Stodden et al., which suggests that the association between PA and FMS could be in the opposite direction for young children [18]. Our findings suggest prior time spent in MVPA is more important to the current level of FMS, than the prior motor skill level is for the current amount of MVPA when children are between the age of ≈5–8. Stodden and co-workers also hypothesised that the relationships between FMS and PA strengthen as children age and develop [18]. Therefore, we would expect several interactions of age for the prospective associations between PA and FMS. However, no such interactions were present in our material. It should be kept in mind, though, that the lack of interactions could result from the narrow age-span of the included children. Importantly, as previous evidence mainly is derived from older children, more longitudinal studies starting at an early age, and with longer follow-up duration, are needed to investigate the moderating effect of age on the bi-directional relationship between PA and FMS in children.

Limited research has targeted the development in PA during the years of preschool and early primary school. Some studies have shown an increase in TPA and

Table 3 Prospective associations between fundamental motor skills at baseline (exposure) and physical activity at follow-up (outcome) (*n* = 224)

		Outcome at follow-up					
		TPA ([cpm])	SED	LPA	MPA	VPA	MVPA
Exposure at baseline	Locomotor skills	0.06 (−0.08, 0.19) *p* = 0.422	0.001 (− 0.07, 0.07) *p* = 0.989	−0.07 (− 0.18, 0.05) *p* = 0.239	−0.02 (− 0.15, 0.11) *p* = 0.734	0.06 (− 0.08, 0.20) *p* = 0.386	0.02 (− 0.11, 0.15) *p* = 0.706
	Object control skills	0.05 (− 0.08, 0.17) *p* = 0.472	0.01 (− 0.06, 0.07) *p* = 0.879	−0.08 (− 0.19, 0.03) *p* = 0.138	0.04 (− 0.09, 0.16) *p* = 0.557	0.06 (− 0.07, 0.18) *p* = 0.374	0.05 (− 0.07, 0.17) *p* = 0.385
	Balance skills	−0.06 (− 0.19, 0.07) *p* = 0.351	0.04 (− 0.04, 0.11) *p* = 0.348	−0.10 (− 0.21, 0.02) *p* = 0.114	−0.08 (− 0.21, 0.05) *p* = 0.214	−0.04 (− 0.17, 0.09) *p* = 0.532	−0.06 (− 0.19, 0.06) *p* = 0.308

All values are standardized β coefficients (95% CI), analysed with a linear mixed model. The models are adjusted for sex, baseline age, baseline body mass index, parental education- and income level, FMS assessor at baseline, accelerometer wear time at baseline and follow-up, and baseline value of the outcome. *TPA* Total physical activity, *cpm* Counts per minute, *SED* Sedentary behaviour, *LPA* Light physical activity, *MPA* Moderate physical activity, *VPA* Vigorous physical activity, *MVPA* Moderate-to-vigorous physical activity. *P*-value is statistic significant to the level of $P < 0.05$

MVPA by age [24, 28, 43, 44], while others have found substantial declines in TPA and MVPA over time [45]. Findings from the present study support those of others showing that PA increases by age in young children, however, in the present study, the development in PA were highly dependent on the children's age and sex. The change in both TPA, MPA, VPA, and MVPA from baseline to follow-up were greater in boys compared to girls. Not only are boys in general more physically active than girls [2, 30, 40], but they also exhibit a greater increase in PA by age, as previously shown over a 10 month period for the current sample [30]. Furthermore, the younger children had considerably greater increase in PA of higher intensities over time when compared to the older children. Also, the older children had a greater positive development in SED when compared to the younger children. Moreover, when investigating development in PA by age we find almost no change in MVPA in the oldest children (≈8 years at follow-up) when compared to the other age groups (Fig. 1). These results are in line with previous research [2], showing a peak in PA levels around the age of 5–6. Such findings are not surprising as the decline in PA is likely related to the transition from preschool to primary school, which is related to both environmental, social, and behavioural changes, and thus different opportunities for PA [2].

As expected, FMS improved over 2 years. The younger children had a greater increase in object control skills than the older, which makes sense as such skills are more advanced than locomotor and balance skills [12] likely to improve at a later stage of development (i.e., normally by age). Whereas previous studies have suggested that boys develop certain FMS' earlier than girls [46, 47], we did not observe any sex differences in the development of FMS herein. As sex-differences in FMS are evident in older children [41], the preschool years could be seen as a window of opportunity in terms of promoting motor development in girls.

Strengths and limitations

We regard the prospective study design including measurements of both PA and FMS at two time points, which allowed for bi-directional analyses of these variables' reciprocal relationships, a major strength of the present study. Importantly, this protocol provide stronger prospective evidence than some previous studies that have not been able to adjust for baseline levels of the outcome [24, 25, 28]. Thus, our results allow for strong inference of causality, although confounding cannot be excluded. Still, we accounted for several potential covariates (sex, age, BMI, parental income and education level, accelerometer wear time, and rater for FMS testing) to limit confounding. The follow-up time of 2 years is relatively long when compared to the majority of previous studies, especially considering the children's young age. Additionally, the multiple PA measurements at baseline, the long monitoring periods (14 days), and the high compliance to the accelerometer protocol provides a solid foundation for investigating the focused relationships.

However, our results should be interpreted with some limitations in mind. It is possible that the null finding in terms of FMS being a predictor of future PA could be influenced by the difference in measurement error and, thus, sensitivity in measurement methods. Because the PA assessment at baseline consisted of up to 6 weeks of objective PA registration, which possibly provided a more precise estimate of PA compared to the single FMS assessment (at both time points), the results could be subject to differing measurement error and differing regression dilution bias [48]. When the more imprecise variable is modelled as the outcome the magnitude of effect is estimated accurately, but with wider confidence intervals [48]. In contrast, when the more imprecise variable is modelled as the exposure it tends to attenuate the regression coefficient [48]. In addition, FMS is a set of 'building blocks' of more advanced complex movements that is conceptualised, operationalised, and measured in different ways across studies [14]. Thus, FMS is hard both to define and to measure accurately.

A general limitation with accelerometer data is that they do not provide a true measure of true SED time or very high PA intensities, nor a correct classification of intensity in certain activities (e.g., cycling, swimming) [49]. Moreover, reporting of raw acceleration, which was not done for the present study, could improve comparability with future studies. Our findings should therefore be interpreted with limited classification accuracy of PA intensity and posture allocation taken into account. Another important issue in accelerometer data reduction and scoring is the choice of epoch length. Because children's natural PA pattern is rather sporadic, with bouts of PA generally lasting < 10 s [50–53], it has been concluded that studies should apply shorter epochs than the traditional 60-s epoch duration to capture PA correctly [49]. Therefore, we used 1-s epochs to avoid loss of information and misclassification of PA intensity in the present study.

There is no established 'gold standard' of assessment of FMS in children [54]. In the present study, we used a test battery inspired by the TGMD-3 [35] as the TGMD-battery is widely used in preschoolers [54, 55]. However, the TGMD was developed in the USA and contains particular movement tasks that are less culturally relevant in Norway (e.g., the baseball strike and bouncing ball). Furthermore, the test does not contain balance tasks. To be able to measure FMS in a large study sample ($N = 1308$ children in the main sample of

PRESPAS) and at the same time cover the three recognised domains of FMS [37, 38], we choose to modify and extend the TGMD-3. Thus, our results are limited by a lack of comparability with other studies using the TGMD-3. Moreover, the balance items included from the PGMQ [37] are only validated for children aged 3–6 years, and therefore not suited for approximately half of our sample at follow-up (mean age: 6.4 (0.9) years). Although we acknowledge this limitation, the mean values and SDs (Table 1) indicates no clear ceiling effect at follow-up.

The average parental educational level among children included in the analyses was higher than among the excluded children, and our sample was highly homogenous in terms of ethnicity and environmental factors. Also, a considerable number of children (*n* = 159 and *n* = 152 for the prospective analyses presented in Table 2 and 3, respectively) were excluded from the main analyses because of missing data in either predictors, outcomes or co-variates at baseline or follow-up. However, differences between included and excluded children were minor at baseline. Furthermore, our sample consisted of healthy children without known disabilities that could affect PA levels or FMS performance. This mean that caution should be exercised in generalising the results to populations comprising ethnic minorities, children with developmental disorders, or populations with lower SES.

Perspectives

Our results suggest that an increased focus on promotion of MVPA during the preschool years can improve development of FMS. Given the additional benefits of MVPA on physical health and cognitive and social development during the early years [5], promotion of MVPA should be a priority public health strategy in this age group – ideally implemented in preschool and school settings where a large number of children can be reached regardless of social background.

As previously reported for this study material [31], the preschool arena is important for children's MVPA. However, findings indicate that this environment stimulates boys, older children, and highly active children more successfully in terms of higher MVPA levels during preschool hours [31]. Even though sex and age are not modifiable factors, it is important that PA programs and social and physical environments (which are modifiable factors) are designed to provide opportunities for all children to increase their MVPA.

Conclusions

In conclusion, PA of moderate to vigorous intensity predicted development of FMS in young children. In contrast, FMS did not predict future PA levels. Furthermore, FMS and MVPA increased by age within this sample of preschoolers, however, the development in PA is highly dependent on children's sex and age. Our results highlight the importance of promoting MVPA for FMS development in children during the preschool years.

Supplementary information

Supplementary information accompanies this paper at https://doi.org/10.1186/s12966-019-0902-6.

Additional file 1: Table S1. Prospective associations between exposing factors (sex and age) at baseline and physical activity at follow-up.

Additional file 2: Table S2. Prospective associations between exposing factors (sex and age) at baseline and fundamental motor skills at follow-up.

Additional file 3: Figure S1. The development in physical activity and sedentary behaviour over two years by sex and age (median split) in children attending preschool at baseline. Figure A: change in sedentary behaviour (SED); Figure B: change in light physical activity (LPA); Figure C: change in moderate physical activity (MPA); Figure D: change in vigorous physical activity.

Additional file 4: Table S4. Cross-sectional associations (main effects) between PA and FMS at follow-up.

Additional file 5: Table S3. Cross-sectional associations (main effects) between PA and FMS at baseline.

Additional file 6: Table S5. Mean sum scores (95% CI) at baseline and at follow-up for the specific items included in the evaluation of fundamental motor skills according to children's age.

Abbreviations

BMI: Body Mass Index; cpm: Counts per minute; FMS: Fundamental motor skills; ICC: Intra-class correlation; LPA: Light physical activity; Min: Minutes; MPA: Moderate physical activity; MVPA: Moderate-to-vigorous physical activity; PA: Physical activity; SD: Standard deviation; SED: Sedentary behaviour; SES: Socioeconomic status; TPA: Total physical activity; VPA: Vigorous physical activity

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Authors' contributions

EAA designed and obtained funding for the study. EAA, KNA, SAA and AKON were involved in the development of the research questions. AKON, EY, KJ, and JML performed the data collection. AKON and EAA analysed the data. AKON drafted the manuscript. All authors contributed to the interpretation of data and were involved in critical revisions of the manuscript. All authors read and approved the final version.

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Availability of data and materials

The datasets used and analysed for the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

Parents of all participating children received oral and written information about the study and provided written consent prior to testing. The Norwegian Centre for Research Data (NSD) approved the study (reference number 39061 and 48016). For Norwegian projects that are not considered medical research, issues concerning data and privacy protection are handled by the NSD according to the Personal Information Act of 2018 and former legislation. In such cases, no requirement of ethical preapproval from a national or regional committee is required.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Publisher's Note

Supplementary Table 1) *Prospective associations between exposing factors (sex and age) at baseline and physical activity at follow-up (n=234).*

		Outcome at follow-up					
		TPA ([cpm])	**SED**	**LPA**	**MPA**	**VPA**	**MVPA**
Exposure at baseline	**Sex**	**p=0.013**	**p=0.038**	p=0.108	**p<0.001**	**p=0.008**	**p<0.001**
	Girls (ref.)	--	--	--	--	--	--
	Boys	43.7 (9.3, 78.0)	-6.0 (-11.6, -0.3)	2.7 (-0.6, 6.0)	3.4 (1.8, 5.0)	2.8 (0.7, 4.8)	6.2 (3.0, 9.4)
	Baseline age (years)	**p trend <0.001**	**p trend <0.001**	**p trend <0.001**	**p trend=0.003**	**p trend <0.001**	**p trend <0.001**
	6 years (ref.)	--	--	--	--	--	--
	5 years	34.0 (-12.4, 80.4)	-9.1 (-16.6, -1.6)	1.3 (-3.2, 5.7)	1.8 (-0.3, 3.8)	1.8 (-1.0, 4.5)	3.5 (-0.7, 7.8)
		p=0.150	**p=0.017**	p=0.566	p=0.097	p=0.208	p=0.105
	4 years	52.5 (2.0, 103.0)	-12.1 (-20.0, -4.1)	5.6 (0.8, 10.3)	1.7 (-0.5, 3.9)	3.6 (0.5, 6.6)	5.3 (0.6, 9.9)
		p=0.042	**p=0.003**	**p=0.022**	p=0.134	**p=0.021**	**p=0.026**
	3 years	104.0 (44.1, 163.9)	-23.6 (-33.0, -14.1)	8.4 (2.7, 14.0)	3.5 (0.9, 6.2)	6.9 (3.3, 10.5)	10.4 (4.9, 15.9)
		p<0.001	**p<0.001**	**p=0.004**	**p=0.010**	**p<0.001**	**p<0.001**

Results from a linear mixed model. The models are adjusted for sex, baseline age, baseline body mass index, parental education- and income level, baseline- and follow-up accelerometer wear time, and baseline value of the outcome. Results are reported as beta coefficients/minutes per day (95 % CI) relative to reference value, or as change per year. TPA: total physical activity; cpm: counts per minute; SED: sedentary behaviour; LPA: light physical activity; MPA: moderate physical activity; VPA: vigorous physical activity; MVPA: moderate-to-vigorous physical activity. *P*-value in bold is statistic significant to the level of *P*<0.05.

Supplementary Table 2*) Prospective associations between exposing factors (sex and age) at baseline and fundamental motor skills at follow-up (n=217).*

		Outcome at follow-up		
		Locomotor	**Object control**	**Balance**
Exposure at baseline	**Sex**	p=0.585	p=0.354	p=0.632
	Girls (ref.)	--	--	--
	Boys	0.07 (-10.18, 0.32)	0.11 (-0.13, 0.35)	-0.06 (-0.29, 0.17)
	Baseline age (years)	p trend=0.282	**p trend=0.001**	p trend=0.155
	6 years (ref.)	--	--	--
	5 years	-0.31 (-0.64, 0.02) p=0.062	-0.26 (-0.56, 0.05) p=0.101	-0.02 (-0.33, 0.28) p=0.870
	4 years	-0.48 (-0.86, -0.11) **p=0.012**	-0.36 (-0.70, 0.01) **p=0.041**	-0.08 (-0.43, 0.28) p=0.664
	3 years	-0.05 (-0.56, 0.45) p=0.842	-0.88 (-1.31, -0.45) **p<0.001**	-0.48 (-0.94, -0.03) **p=0.036**

Results from a linear mixed model. The models are adjusted for sex, baseline age, baseline body mass index, parental education- and income level, baseline- and follow-up FMS assessor, and baseline value of the outcome. Results are reported as standardized beta coefficients (95 % CI) relative to reference value, or as change per year. *P*-value in bold is statistic significant to the level of *P*<0.05.

Supplementary Table S3: *Cross-sectional associations (main effects) between PA and FMS at baseline (n=303)*

	Locomotor skills	**Object control skills**	**Balance skills**
TPA	0.32 (0.22, 0.42)**	0.20 (0.10, 0.31)**	0.03 (-0.07, 0.13)
SED	-0.24 (-0.38, -0.09)**	-0.18 (0.34, 0.02)*	-0.02 (-0.16, 0.12)
LPA	0.04 (-0.06, 0.14)	0.05 (-0.05, 0.16)	-0.001 (-0.10, 0.09)
MPA	0.26 (0.16, 0.37)**	0.25 (0.14, 0.36)**	0.030 (-0.07, 0.13)
VPA	0.36 (0.26, 0.46)**	0.24 (0.13, 0.35)**	0.03 (-0.07, 0.13)
MVPA	0.34 (0.24, 0.44)**	0.26 (0.15, 0.37)**	0.03 (-0.07, 0.14)

Adjusted associations: sex, age, BMI, parental education- and income level, accelerometer wear time, test person FMS. Estimates are reported as standardized units (95 % CI). TPA: total physical activity; SED: sedentary behaviour; LPA: light physical activity; MPA: moderate physical activity; VPA: vigorous physical activity; MVPA: moderate to vigorous physical activity. ** p<0.01; *p<0.05.

Supplementary Table S4: *Cross-sectional associations (main effects) between PA and FMS at follow-up (n=219)*

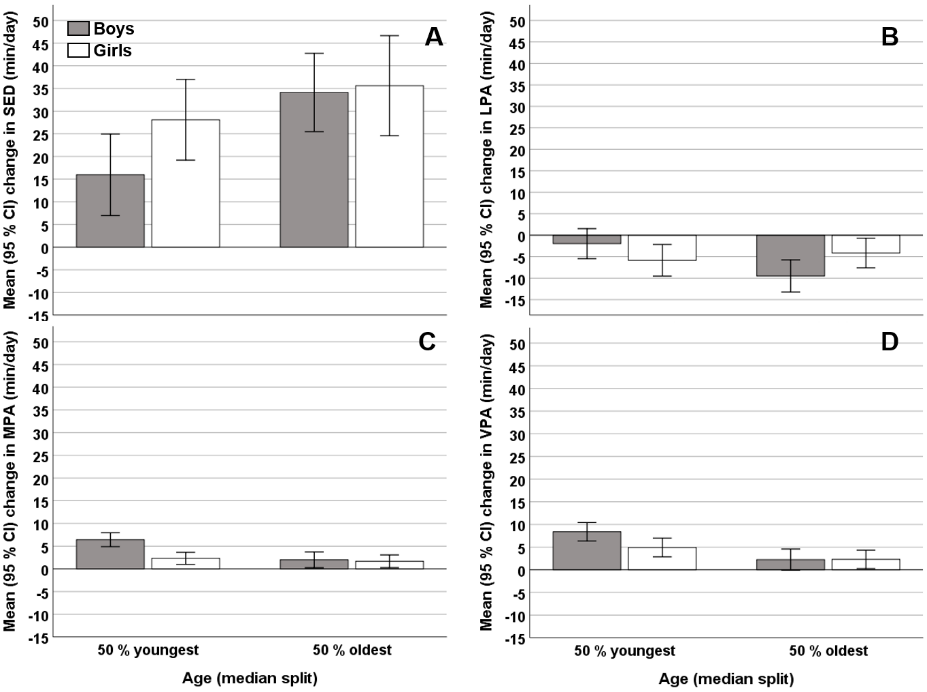
	Locomotor skills	**Object control skills**	**Balance skills**
TPA	0.30 (0.16, 0.43)**	0.20 (0.07, 0.34)**	0.11 (-0.02, 0.25)
SED	-0.20 (-0.42, 0.03)	-0.23 (-0.44, -0.01)*	-0.04 (-0.25, 0.18)
LPA	-0.06 (-0.20, 0.09)	0.04 (-0.10, 0.17)	0.02 (-0.12, 0.16)
MPA	0.17 (0.03, 0.31)*	0.15 (0.01, 0.28)*	0.05 (-0.08, 0.19)
VPA	0.31 (0.18, 0.44)**	0.21 (0.08, 0.34)**	0.10 (-0.03, 0.23)
MVPA	0.28 (0.15, 0.42)**	0.21(0.07, 0.34)**	0.09 (-0.05, 0.23)

Adjusted associations: sex, age, BMI, parental education- and income level, accelerometer wear time, test person FMS. Estimates are reported as standardized units (95 % CI). TPA: total physical activity; SED: sedentary behaviour; LPA: light physical activity; MPA: moderate physical activity; VPA: vigorous physical activity; MVPA: moderate to vigorous physical activity. ** p<0.01; *p<0.05.

Supplementary Table S5: Mean sum scores (95 % CI) at baseline and at follow-up for the specific items included in the evaluation of fundamental motor skills according to children's age (age equivalent, 3-month intervals)

		Test of Gross Motor Development 3						Preschooler Gross Motor Quality Scale		
Age equivalent	**n**	**Run** (4 criteria)	**Horizontal jump** (4 criteria)	**Hop** (4 criteria)	**Two-hand catch** (3 criteria)	**Overhand throw** (4 criteria)	**Kick stationary ball** (3 criteria*)	**Balance one foot** (4 criteria)	**Walk line backward** (4 criteria*)	**Walk line forward** (4 criteria)
Baseline, n= 242										
3-0	4	3.7 (2.2, 5.1)	5.7 (2.2, 5.1)	0.0 (0.0, 0.0)	2.0 (2.0, 2.0)	2.7 (0.2, 5.5)	2.3 (0.9, 3.8)	1.3 (-4.4, 7.1)	3.3 (0.5, 6.2)	3.7 (-1.5, 8.8)
3-3	26	4.2 (3.5, 4.9)	3.8 (3.0, 4.6)	1.4 (0.5, 2.3)	2.0 (1.7, 2.3)	2.7 (2.0, 3.3)	3.1 (2.4, 3.9)	4.2 (3.2, 5.1)	3.7 (3.0, 4.5)	3.1 (2.4, 3.8)
3-6	20	4.5 (3.6, 5.3)	3.7 (2.8, 4.6)	2.4 (1.1, 3.6)	2.4 (1.9, 2.9)	2.4 (1.7, 3.1)	3.4 (2.8, 4.1)	4.4 (3.1, 5.6)	4.9 (4.0, 6.0)	5.1 (3.2, 4.9)
3-9	16	5.3 (4.5, 6.2)	4.9 (3.8, 6.1)	3.8 (2.5, 5.0)	3.2 (2.6, 3.8)	2.8 (2.1, 3.4)	3.3 (2.6, 4.0)	4.6 (3.4, 5.8)	4.6 (3.6, 5.5)	4.3 (3.3, 5.2)
4-0	14	5.5 (4.8, 6.2)	4.5 (3.4, 5.6)	2.9 (1.8, 4.1)	2.4 (1.9, 3.0)	3.5 (2.8, 4.2)	3.2 (2.6, 3.9)	5.5 (4.1, 6.9)	5.1 (4.4, 5.8)	4.4 (3.7, 5.1)
4-3	17	5.4 (4.6, 6.1)	5.8 (4.9, 6.6)	4.6 (3.2, 6.1)	3.5 (2.7, 4.2)	3.1 (2.5, 3.7)	3.7 (2.8, 4.6)	6.2 (5.3, 7.1)	5.5 (5.0, 6.1)	4.6 (4.0, 5.2)
4-6	16	6.1 (5.7, 6.6)	5.5 (4.5, 6,5)	5.1 (4.5, 5.8)	3.3 (2.5, 4.1)	3.6 (3.2, 4.1)	3.3 (2.6, 4.0)	5.4 (4.8, 6.1)	5.6 (5.8, 6.5)	4.8 (3.7, 5.9)
4-9	22	6.0 (5.6, 6.3)	6.0 (5.2, 6.7)	5.5 (4.7, 6.3)	3.5 (2.9, 4.1)	3.3 (2.7, 3.9)	3.8 (3.2, 4.4)	6.6 (6.0, 7.1)	5.7 (5.2, 6.3)	5.3 (4.6, 6.1)
5-0	24	5.9 (5.3, 6.5)	5.1 (4.1, 6.0)	4.7 (3.7, 5.6)	3.6 (3.0, 4.2)	3.3 (2.7, 3.8)	4.3 (3.7, 4.8)	5.9 (4.7, 6.1)	5.5 (4.6, 6.4)	5.9 (5.2, 6.6)
5-3	20	5.9 (5.3, 6.5)	5.3 (4.4, 6.1)	5.9 (5.2, 6.7)	4.1 (3.4, 4.8)	3.3 (2.7, 3.9)	4.2 (3.4, 4.9)	6.3 (5.4, 7.1)	6.4 (5.8, 7.1)	6.3 (5.6, 7.1)
5-6	28	6.5 (5.9, 7.1)	5.5 (4.9, 6.2)	5.5 (4.7, 6.3)	3.6 (3.0, 4.3)	3.2 (2.5, 3.8)	4.5 (4.0, 5.0)	6.9 (6.3, 7.5)	6.4 (6.0, 6.8)	6.6 (6.0, 7.1)
5-9	27	5.6 (5.1, 6.1)	6.0 (5.4, 6.6)	5.7 (5.1, 6.3)	4.1 (3.5, 4.6)	3.7 (3.1, 4.2)	4.3 (3.7, 4.8)	6.9 (6.4, 7.4)	6.6 (6.0, 7.1)	6.6 (5.9, 7.3)
6-0	8	7.4 (6.6, 8.1)	5.8 (4.2, 7.3)	5.8 (3.8, 7.7)	4.6 (3.4, 5.8)	4.0 (2.7, 5.3)	4.1 (3.4, 4.8)	6.8 (5.4, 8.1)	6.8 (5.4, 8.1)	6.4 (5.0, 7.8)
Follow-up, n= 242										
4-9	15	6.1 (5.1 7.0)	4.5 (3.9, 5.2)	4.1 (3.2, 5.0)	4.8 (3.9, 5.7)	5.4 (4.4, 6.4)	4.3 (3.5, 5.2)	5.3 (3.6, 6.9)	6.1 (5.3, 7.0)	5.7 (4.5, 6.8)
5-0	24	6.2 (5.4, 6.9)	4.7 (4.0, 5.4)	4.0 (3.1, 4.9)	5.5 (5.1, 5.9)	5.0 (4.2, 5.9)	4.3 (3.5, 5.1)	5.3 (4.2, 6.5)	6.9 (6.4, 7.5)	6.8 (6.1, 7.5)
5-3	12	5.4 (4.3, 6.5)	4.1 (3.1, 5.0)	4.8 (3.3, 6.4)	5.3 (4.5, 6.2)	5.8 (5.0, 6.6)	4.9 (4.0, 5.8)	7.5 (6.9, 8.1)	6.7 (6.0, 7.3)	6.0 (4.8, 7.2)
5-6	17	5.8 (4.7, 6.8)	4.8 (3.8, 5.8)	4.3 (3.2, 5.4)	5.9 (5.9, 6.1)	6.3 (5.6, 7.0)	4.6 (3.8, 5.4)	6.6 (5.3, 7.9)	7.1 (6.5, 7.7)	6.8 (5.9, 7.6)
5-9	14	6.1 (5.2, 6.9)	5.3 (4.2, 6.3)	4.6 (3.5, 5.6)	5.6 (5.2, 6.1)	6.1 (5.2, 7.0)	4.6 (3.8, 5.5)	7.0 (5.7, 8.3)	6.6 (6.1, 7.2)	6.8 (6.0, 7.6)
6-0	15	5.4 (4.4, 6.4)	4.3 (3.2, 5.4)	3.9 (2.9, 5.0)	5.4 (4.4, 6.4)	6.0 (5.3, 6.7)	4.5 (3.2, 5.9)	7.5 (7.0, 8.1)	6.5 (5.4, 7.6)	7.1 (6.3, 7.9)
6-3	23	6.8 (6.1, 7.4)	5.3 (4.3, 6.2)	5.1 (4.0, 6.2)	5.9 (5.6, 6.1)	5.6 (4.7, 6.5)	5.2 (4.7, 5.7)	7.6 (7.0, 8.1)	6.9 (6.3, 7.4)	7.5 (7.0, 8.0)
6-6	20	6.7 (5.9, 7.4)	4.6 (3.4, 5.9)	4.8 (3.9, 5.7)	5.8 (5.6, 6.1)	6.1 (5.4, 6.8)	5.2 (4.4, 6.0)	7.6 (7.0, 8.1)	7.3 (6.9, 7.8)	7.4 (6.8, 8.0)
6-9	21	6.7 (6.0, 7.4)	5.1 (4.2, 6.0)	5.3 (4.5, 6.2)	5.7 (5.1, 6.3)	6.1 (5.4, 6.8)	5.6 (5.2, 5.9)	7.2 (6.3, 8.2)	6.8 (6.2, 7.4)	7.4 (6.9, 7.9)
7-0	21	6.5 (5.6, 7.4)	5.4 (4.7, 6.1)	4.9 (4.1, 5.7)	5.7 (5.1, 6.3)	6.5 (5.8, 7.3)	5.5 (5.0, 6.0)	7.1 (6.3, 8.0)	7.1 (6.5, 7.7)	7.3 (6.8, 7.9)
7-3	25	6.5 (5.8, 7.3)	5.8 (5.3, 6.3)	5.7 (4.8, 6.5)	5.7 (5.9, 6.0)	6.5 (5.9, 7.1)	5.5 (5.2, 5.9)	7.9 (7.7, 8.1)	7.0 (6.5, 7.4)	7.7 (7.4, 8.0)
7-6	31	6.2 (5.5, 6.8)	6.2 (5.6, 6.7)	6.2 (5.5, 6.9)	6.0 (6.0, 6.0)	6.8 (6.4, 7.3)	5.6 (5.2, 6.0)	7.7 (7.3, 8.1)	7.2 (6.9, 7.6)	7.4 (7.0, 7.7)
7-9	4	6.8 (5.2, 8.3)	5.8 (3.7, 7.8)	6.5 (3.5, 9.5)	5.4 (4.4, 6.4)	5.0 (0.9, 9.1)	6.0 (6.0, 6.0)	8.0 (8.0, 8.0)	7.5 (5.9, 9.1)	8.0 (8.0, 8.0)

All values are reported as means (95 % confidence intervals). The presented scores are means of sum of two trials per FMS item for children in the associated age-ranges. Maximum score 4 criteria: 8; maximum score 3 criteria: 6. Age equivalents reported in three month intervals according to the TGMD-3 protocol, e.g.: 3-0 = 3 years 0 months up to 3 years 3 months; 3-3 = 3 years and 3 months up to 3 years and 6 months; 3-6= 3 years 6 months up to 3 years 9 months; 3-9= 3 years 9 months up to 4 years. *For the item "kick stationary ball" the original criteria number 2 (*child takes an elongated stride or leap just prior to ball contact*) was not evaluated, i.e. the score is based on the three remaining criteria (Ulrich et al., 2019); For the item "walk on line backward" the original criteria number B43 (*steps on line precisely without trial*) was not evaluated, i.e. the score is based on the four remaining criteria (Sun et al., 2010).



Supplementary figure 1. *The development in physical activity and sedentary behaviour over two years by sex and age (median split) in children attending preschool at baseline. Figure A: change in sedentary behaviour (SED); Figure B: change in light physical activity (LPA); Figure C: change in moderate physical activity (MPA); Figure D: change in vigorous physical activity.*

APPENDIX I

Norsk samfunnsvitenskapelig datatjeneste AS
NORWEGIAN SOCIAL SCIENCE DATA SERVICES

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Eivind Aadland
Institutt for idrett Høgskulen i Sogn og Fjordane
Pb 133
6856 SOGNDAL

Vår dato: 24.09.2014	Vår ref: 39061 / 3 / LT	Deres dato:	Deres ref:

TILBAKEMELDING PÅ MELDING OM BEHANDLING AV PERSONOPPLYSNINGER

Vi viser til melding om behandling av personopplysninger, mottatt 19.06.2014. Meldingen gjelder prosjektet:

39061	*Fysisk aktivitet hjå 3-5 år gamle barnehagebarn i Sogn og Fjordane*
Behandlingsansvarlig	*Høgskulen i Sogn og Fjordane, ved institusjonens øverste leder*
Daglig ansvarlig	*Eivind Aadland*

Personvernombudet har vurdert prosjektet, og finner at behandlingen av personopplysninger vil være regulert av § 7-27 i personopplysningsforskriften. Personvernombudet tilrår at prosjektet gjennomføres.

Personvernombudets tilråding forutsetter at prosjektet gjennomføres i tråd med opplysningene gitt i meldeskjemaet, korrespondanse med ombudet, ombudets kommentarer samt personopplysningsloven og helseregisterloven med forskrifter. Behandlingen av personopplysninger kan settes i gang.

Det gjøres oppmerksom på at det skal gis ny melding dersom behandlingen endres i forhold til de opplysninger som ligger til grunn for personvernombudets vurdering. Endringsmeldinger gis via et eget skjema, http://www.nsd.uib.no/personvern/meldeplikt/skjema.html. Det skal også gis melding etter tre år dersom prosjektet fortsatt pågår. Meldinger skal skje skriftlig til ombudet.

Personvernombudet har lagt ut opplysninger om prosjektet i en offentlig database, http://pvo.nsd.no/prosjekt.

Personvernombudet vil ved prosjektets avslutning, 31.12.2020, rette en henvendelse angående status for behandlingen av personopplysninger.

Vennlig hilsen

Katrine Utaaker Segadal

Lis Tenold

Kontaktperson: Lis Tenold tlf: 55 58 33 77
Vedlegg: Prosjektvurdering

Dokumentet er elektronisk produsert og godkjent ved NSDs rutiner for elektronisk godkjenning.

Personvernombudet for forskning

Prosjektvurdering - Kommentar

Prosjektnr: 39061

Utvalget informeres skriftlig og muntlig om prosjektet og det innhentes skriftlig samtykke til deltakelse. Informasjonsskrivene mottatt 23.09.2014 finner personvernombudet er godt utformet. Foreldre samtykker samtykker skriftlig til at deres barn kan delta.

Det behandles sensitive personopplysninger om helseforhold, jf. personopplysningsloven § 2 punkt 8 c).

Det legges til grunn at barnehagepersonell ikke skal gi opplysninger om identifiserbare barnehagebarn.

Personvernombudet legger til grunn at forsker etterfølger Høgskulen i Sogn og Fjordane sine interne rutiner for datasikkerhet. Dersom personopplysninger skal lagres på mobile enheter, bør opplysningene krypteres tilstrekkelig.

Innsamlede opplysninger om personalet vil bli anonymisert senest 31.12.2020. For opplysninger om foreldre og barn ønskes datamaterialet oppbevart med personidentifikasjon etter prosjektslutt 31.12.2020 i påvente av oppfølgningsundersøkelse/er, foreløpig frem til utgangen av 2027. Det vil bli innhentet skriftlig samtykke fra foresatte for dette.

Personvernombudet forutsetter at nye oppfølgningsundersøkelser meldes i god tid før oppstart og kontakt med utvalget.

Norsk samfunnsvitenskapelig datatjeneste AS
NORWEGIAN SOCIAL SCIENCE DATA SERVICES

NSD

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Eivind Aadland
Institutt for idrett
Høgskulen i Sogn og Fjordane
Pb 133
6856 SOGNDAL

Vår dato: 23.04.2015 Vår ref: 39061/5/LT/LR Deres dato: Deres ref:

BEKREFTELSE PÅ ENDRING

Vi viser til endringsmelding mottatt 13.04.2014 for prosjektet;

39061 Fysisk aktivitet hjå 3-5 år gamle barnehagebarn i Sogn og Fjordane

Det vises videre til telefonsamtale 23.04.2015.

Personvernombudet tar til orientering og registrerer følgende endringer;

1. Utvalget utvides fra 1200 barn og 40 barnehager til 1900 barn og 80 barnehager.
2. Datainnsamling er utsatt nå til våren 2016.
3. Måling av fysisk aktivitet med aktivitetsmålerer er utvidet fra 7 til 14 dagar for å øke målingene sin reliabilitet.
4. En vil inkludere vurdering av motoriske ferdigheter hos barna, og vil til dette benytte testbatteri (Test of Gross Motor Development-3: Ulrich, 2015) som består av 13 ulike ferdigheter (løping, hopping, hinking, kast, mottak og spark av ball i ulike varianter).
5. Et utvalg barn (om lag 25%) vil bli invitert til å gjennomføre aktivitetsmåling 3 ganger i løpet av barnehageåret: haust, vinter, vår/sommer.

Prosjektleder har lagt ved oppdaterte informasjonsskriv. Personvernombudet finner skrivet tilfredsstillende.

Personvernombudet vil ved prosjektslutt, 31.12.2020, rette en henvendelse vedrørende status for videre behandling av personopplysninger.

Ta gjerne kontakt dersom noe er uklart.

Vennlig hilsen

Bjørn Henrichsen

Lis Tenold

APPENDIX II

Eivind Aadland
Institutt for idrett Høgskulen i Sogn og Fjordane
Pb 133
6856 SOGNDAL

Vår dato: 02.05.2016 Vår ref: 48016 / 3 / HJP Deres dato: Deres ref:

TILBAKEMELDING PÅ MELDING OM BEHANDLING AV PERSONOPPLYSNINGER

Vi viser til melding om behandling av personopplysninger, mottatt 17.03.2016. Meldingen gjelder prosjektet:

48016	*Fysisk aktivitet hjå barnehagebarn i Sogn og Fjordane (PRESPAS) - Oppfylging 2016 - 2019*
Behandlingsansvarlig	*Høgskulen i Sogn og Fjordane, ved institusjonens øverste leder*
Daglig ansvarlig	*Eivind Aadland*

Personvernombudet har vurdert prosjektet, og finner at behandlingen av personopplysninger vil være regulert av § 7-27 i personopplysningsforskriften. Personvernombudet tilrår at prosjektet gjennomføres.

Personvernombudets tilråding forutsetter at prosjektet gjennomføres i tråd med opplysningene gitt i meldeskjemaet, korrespondanse med ombudet, ombudets kommentarer samt personopplysningsloven og helseregisterloven med forskrifter. Behandlingen av personopplysninger kan settes i gang.

Det gjøres oppmerksom på at det skal gis ny melding dersom behandlingen endres i forhold til de opplysninger som ligger til grunn for personvernombudets vurdering. Endringsmeldinger gis via et eget skjema, http://www.nsd.uib.no/personvern/meldeplikt/skjema.html. Det skal også gis melding etter tre år dersom prosjektet fortsatt pågår. Meldinger skal skje skriftlig til ombudet.

Personvernombudet har lagt ut opplysninger om prosjektet i en offentlig database, http://pvo.nsd.no/prosjekt.

Personvernombudet vil ved prosjektets avslutning, 31.12.2021, rette en henvendelse angående status for behandlingen av personopplysninger.

Vennlig hilsen

Kjersti Haugstvedt

Hanne Johansen-Pekovic

Kontaktperson: Hanne Johansen-Pekovic tlf: 55 58 31 18
Vedlegg: Prosjektvurdering

Dokumentet er elektronisk produsert og godkjent ved NSDs rutiner for elektronisk godkjenning.

Personvernombudet for forskning

Prosjektvurdering - Kommentar

Prosjektnr: 48016

FORMÅL

Prosjektet er en oppfølgingsstudie til prosjektet "Fysisk aktivitet hjå barnehagebarn i Sogn og Fjordane utført i barnehageåret 2015/2016.
Føremålet med dette prosjektet er å kartlegge utvikling i fysisk aktivitetsnivå blant 3 til 8 år gamle barn, innhente kunnskap om hva som kan fremme fysisk aktivitet blant barn, og undersøke mulige sammenhenger mellom fysisk aktivitet, motorikk og vektstatus.

UTVALG OG REKRUTTERING

Utvalget vil bestå av omtrent 400 barnehagebarn og deres foresatte. Kontaktopplysninger til foresatte er allerede innsamlet gjennom prosjektet PRESPAS, og de foresatte ga da samtykke til kontakt for oppfølgingsstudier.

DATAINNSAMLING

Datamaterialet vil bli samlet inn ved spørreskjema på papir, og informasjon fra en skritteller. Barna skal bruke skrittelleren to uker i året, i totalt tre år.

INFORMASJON OG SAMTYKKE

Utvalget informeres skriftlig om prosjektet og samtykker til deltakelse. Informasjonsskrivet er godt utformet.

BARN I FORSKNING

Merk at når barn skal delta aktivt, er deltagelsen alltid frivillig for barnet, selv om de foresatte samtykker. Barnet bør få alderstilpasset informasjon om prosjektet, og det må sørges for at de forstår at deltakelse er frivillig og at de når som helst kan trekke seg dersom de ønsker det.

SENSITIVE PERSONOPPLYSNINGER

Det behandles sensitive personopplysninger om helseforhold.

INFORMASJONSSIKKERHET

Vi legger til grunn at behandlingen av personopplysninger er i samsvar med interne retningslinjer for informasjonssikkerhet ved Høgskulen i Sogn og Fjordane.

PROSJEKTSLUTT OG LAGRING AV DATA

Forventet prosjektslutt er 31.12.2021. Ifølge prosjektmeldingen skal innsamlede opplysninger da oppbevares med personidentifikasjon til 31.12.2027 for oppfølgingsstudier/videre forskning.

APPENDIX III

HØGSKULEN i
SOGN OG FJORDANE

Sogn og Fjordane
PRESPAS
Fysisk aktivitet hjå barnehagebarn

Kjære foreldre/føresette for barn i ein barnehage i Sogn og Fjordane **Sogndal, 7. april 2015**

Førespurnad om deltaking i forskingsprosjektet
«*Fysisk aktivitet hjå barnehagebarn i Sogn og Fjordane*»

Bakgrunn og føremål med prosjektet

Fysisk aktivitet er viktig for barn si normale fysiske, psykiske og sosiale utvikling, men det finnast lite kunnskap om fysisk aktivitet og fysisk aktiv leik hjå barnehagebarn i Noreg. Føremålet med dette prosjektet er å

- Kartlegge fysisk aktivitetsnivå og fysisk aktiv leik hjå 3-5 år gamle barn i barnehagen
- Innhente kunnskap om kva som fremjar fysisk aktivitet og fysisk aktiv leik i barnehagen

Prosjektet er planlagt å omfatte om lag 2000 barn i halvparten av kommunane i Sogn og Fjordane.

Kva inneber studien for barnet og for deg/dykk som foreldre/føresette?

Studien inneber at dykkar barn vil gå med ein aktivitetsmålar som barnet skal bere i eit belte rundt livet frå morgon til kveld i 14 påfølgjande dagar. Aktivitetsmålaren skal kun takast av når barnet er i vatn (badar eller dusjar), i tillegg til om natta, men vil elles ikkje påverke barnet sin kvardag. Aktivitetsmålaren er på storleik med ei fyrstikkøskje, og blir levert ut og henta inn i barnehagen. Det vil også bli gjort ei vurdering av barnet sine motoriske ferdigheiter i kjende rørslemønster som løping, hopping og hinking, samt kast, mottak og spark av ball. Måling av vekt og høgde gjerast i samarbeid mellom personalet i barnehagen og prosjektmedarbeidarar. Du/de som foreldre/føresette vil bli spurde om å fylle ut eit kort spørjeskjema med spørsmål om barnet (fødselsvekt, evt sjukdomar eller medisinske problem og etnisitet) og dykkar ansvarsfordeling for barnet, alder, vekt, høgd, sivil status, utdanning og fysisk aktivitet.

Tre av barnehagane som er med i prosjektet vil bli plukka ut for observasjon av barna sin fysisk aktiv leik, og i nokre av observasjonane vil det bli nytta bilet og video. Dette vil gå føre seg fem dagar haust/vinter og fem dagar vår/sommar. Det vil bli gitt informasjon om dette til foreldre/føresette i dei barnehagane det gjeld. Me vil hente inn nytt samtykke for denne delen av studien på eit seinare tidspunkt.

Tidsrom:

Datainnsamling er planlagt å gå føre seg frå hausten 2015 til våren 2016.

Studien omhandlar:

- Måling av fysisk aktivitetsnivå, motoriske ferdigheiter, vekt og høgd hjå barna og personale i barnehagane
- Kartlegging av fysiske, materielle og sosiale faktorar i barnehagen
- Innhenting av bakgrunnsinformasjon (kort spørjeskjema) frå foreldra
- Observasjon og videoopptak av barn i fysisk aktiv leik og intervju av personalet om leik i eit utval barnehagar

Kva skjer med informasjonen om dykk?

Alle data som vert samla inn, både papirbasert og elektronisk, vert handsama i samsvar med krav til personvern og IKT-tryggleik nedfelt i personopplysningslova. Informasjonen som vert registrert om dykkar barn, skal berre nyttast i henhald til føremålet med studien. Alle skjema og data vert avidentifisert, som vil seie at dei vert handsama utan namn og fødselsnummer eller andre direkte opplysningar som kan kople informasjon til dykkar barn. Identifiserbare opplysningar som knyter dykkar barn til opplysningane vert erstatta av ein kode. Lista som koplar kode og namn vert oppbevart på ein sikker måte åtskilt frå forskingsdata, og berre prosjektleiinga har tilgang til namnelista og det er berre dei som kan finne attende til dykkar barn.

Høgskulen i Sogn og Fjordane ved dekan på Avdeling for Lærarutdanning og Idrett er databehandlingsansvarleg for studien. Forskarar ved Norges Idrettshøgskule og Høgskulen i Oslo og Akershus vil få tilgang til avidentifiserte data.

Kva skjer når data er samla inn?

Resultata frå prosjektet vert publisert i form av engelskspråklege artiklar i internasjonal faglitteratur og norske publikasjonar i form av populærvitskaplege artiklar og faglege føredrag. Me understrekar at opplysningar som kjem fram i publikasjonar og føredrag ikkje kan førast tilbake til einskilde personar.

Prosjektet skal vere avslutta innan 2020. Etter dette ynskjer me å oppbevare data for framtidige oppfølgingsstudiar. Det finnes i dag lite kunnskap om langtidseffektar av fysisk aktivitet hjå barn. Difor ynskjer me å kunne gjere nye studiar knytt til korleis fysisk aktivitet kan påverke barn og unge sin oppvekst, læring, livsstil og helse seinare. Datamaterialet og kodelista med namn vert frå 2020 oppbevara hjå Norsk Samfunnsvitenskapelig Datatjeneste fram til 2027. Det kan såleis bli aktuelt å spørje om dykkar barn kan delta i nye studiar seinare. Dersom me ynskjer å gjennomføre nye studiar med utgangspunkt i dette materialet, vil de verte informert om hensikta med studien og me vil spørje om nytt samtykke. Ved oppbevaring av data eller gjennomføring av nye studiar etter barnet har fylt 18 år, vil barnet sjølv bli bedt om samtykke.

Frivillig deltaking

Det er frivillig å ta del i studien. Ein kan trekke seg frå prosjektet når som helst og utan å oppgi grunn, og utan at det får negative konsekvensar. Dersom de aksepterer at dykkar barn tek del i studien, underteiknar du samtykkeerklæringa på neste side. Om du seier ja til å vera med no, kan du seinare trekkje tilbake samtykket ditt utan nokon konsekvensar for deg/dykk eller dykkar barn. Dersom du seinare ønskjer å trekke samtykket for dykkar barn eller har spørsmål til studien, ta gjerne kontakt.

Venleg helsing

Eivind Aadland (prosjektleiar), HISF Institutt for Idrett, epost: eivind.aadland@hisf.no; tlf 57676086

Lillian Pedersen, HISF Institutt for Barnehagelærarutdanning, epost: lillian.pedersen@hisf.no ; tlf 57676064

Kjersti Johannessen, HISF Institutt for Idrett, epost: kjerstij@hisf.no; tlf 57676387

Samtykke til deltaking i studien

Eg har lese informasjonsskrivet og aksepterer at mitt barn tek del i studien

----

(Signert av foreldre til prosjektdeltakar, dato)

Barnet sitt førenamn og etternamn: (Skriv tydeleg, helst med blokkbokstavar)

………………………………………………………………………………………….

Foreldre/føresette sitt førenamn og etternamn: (Skriv tydeleg, helst med blokkbokstavar)

………………………………………………………………………………………….

Foreldre/føresette si epost-adresse og mob.tlf nr: (Skriv tydeleg, helst med blokkbokstavar)

………………………………………………………………………………………….

Eg stadfestar at eg har gjeve informasjon om studien

Eivind Aadland 7/4-2015

………………………………………………………………………………………….

(Signert prosjektleiar for studien Eivind Aadland, dato)

APPENDIX IV

HØGSKULEN i SOGN OG FJORDANE

Sogn og Fjordane PRESPAs
Fysisk aktivitet hjå barnehagebarn

Kjære foreldre/føresette for barn i ein barnehage i Sogn og Fjordane

Sogndal, 7. april 2015

Førespurnad om deltaking i forskingsprosjektet *«Fysisk aktivitet hjå barnehagebarn i Sogn og Fjordane»*

Bakgrunn og føremål med prosjektet

Fysisk aktivitet er viktig for barn si normale fysiske, psykiske og sosiale utvikling, men det finnast lite kunnskap om fysisk aktivitet og fysisk aktiv leik hjå barnehagebarn i Noreg. Føremålet med dette prosjektet er å

- Kartlegge fysisk aktivitetsnivå og fysisk aktiv leik hjå 3-5 år gamle barn i barnehagen
- Innhente kunnskap om kva som fremjar fysisk aktivitet og fysisk aktiv leik i barnehagen

Prosjektet er planlagt å omfatte om lag 2000 barn i halvparten av kommunane i Sogn og Fjordane.

Kva inneber studien for barnet og for deg/dykk som foreldre/føresette?

Studien inneber at dykkar barn vil gå med ein aktivitetsmålar som barnet skal bere i eit belte rundt livet frå morgon til kveld i 14 påfølgjande dagar tre gonger i løpet av året (haust, vinter, vår/sommar). Aktivitetsmålaren skal kun takast av når barnet er i vatn (badar eller dusjar), i tillegg til om natta, men vil elles ikkje påverke barnet sin kvardag. Aktivitetsmålaren er på storleik med ei fyrstikkøskje, og blir levert ut og henta inn i barnehagen. På eitt tidspunkt vil det også bli gjort ei vurdering av barnet sine motoriske ferdigheiter i kjende rørslemønster som løping, hopping og hinking, samt kast, mottak og spark av ball. Måling av vekt og høgde gjerast i samarbeid mellom personalet i barnehagen og prosjektmedarbeidarar. Du/de som foreldre/føresette vil bli spurde om å fylle ut eit kort spørjeskjema med spørsmål om barnet (fødselsvekt, evt sjukdomar eller medisinske problem og etnisitet) og dykkar ansvarsfordeling for barnet, alder, vekt, høgd, sivil status, utdanning, inntekt og fysisk aktivitet.

Tre av barnehagane som er med i prosjektet vil bli plukka ut for observasjon av barna sin fysisk aktive leik, og i nokre av observasjonane vil det bli nytta bilet og video. Dette vil gå føre seg fem dagar haust/vinter og fem dagar vår/sommar. Det vil bli gitt informasjon om dette til foreldre/føresette i dei barnehagane det gjeld. Me vil hente inn nytt samtykke for denne delen av studien på eit seinare tidspunkt.

Tidsrom:

Datainnsamling er planlagt å gå føre seg frå hausten 2015 til våren 2016.

Studien omhandlar:

- Måling av fysisk aktivitetsnivå, motoriske ferdigheiter, vekt og høgd hjå barna og personale i barnehagane
- Kartlegging av fysiske, materielle og sosiale faktorar i barnehagen
- Innhenting av bakgrunnsinformasjon (kort spørjeskjema) frå foreldra
- Observasjon og videoopptak av barn i fysisk aktiv leik og intervju av personalet om leik i eit utval barnehagar

Kva skjer med informasjonen om dykk?

Alle data som vert samla inn, både papirbasert og elektronisk, vert handsama i samsvar med krav til personvern og IKT-tryggleik nedfelt i personopplysningslova. Informasjonen som vert registrert om dykkar barn, skal berre nyttast i henhald til føremålet med studien. Alle skjema og data vert avidentifisert, som vil seie at dei vert handsama utan namn og fødselsnummer eller andre direkte opplysningar som kan kople informasjon til dykkar barn. Identifiserbare opplysningar som knyter dykkar barn til opplysningane vert erstatta av ein kode. Lista som koplar kode og namn vert oppbevart på ein sikker måte åtskilt frå forskingsdata, og berre prosjektleiinga har tilgang til namnelista og det er berre dei som kan finne attende til dykkar barn.

Høgskulen i Sogn og Fjordane ved dekan på Avdeling for Lærarutdanning og Idrett er databehandlingsansvarleg for studien. Forskarar ved Norges Idrettshøgskule og Høgskulen i Oslo og Akershus vil få tilgang til avidentifiserte data.

Kva skjer når data er samla inn?

Resultata frå prosjektet vert publisert i form av engelskspråklege artiklar i internasjonal faglitteratur og norske publikasjonar i form av populærvitskaplege artiklar og faglege føredrag. Me understrekar at opplysningar som kjem fram i publikasjonar og føredrag ikkje kan førast tilbake til einskilde personar.

Prosjektet skal vere avslutta innan 2020. Etter dette ynskjer me å oppbevare data for framtidige oppfølgingsstudiar. Det finnes i dag lite kunnskap om langtidseffektar av fysisk aktivitet hjå barn. Difor ynskjer me å kunne gjere nye studiar knytt til korleis fysisk aktivitet kan påverke barn og unge sin oppvekst, læring, livsstil og helse seinare. Datamaterialet og kodelista med namn vert frå 2020 oppbevara hjå Norsk Samfunnsvitenskapelig Datatjeneste fram til 2027. Det kan såleis bli aktuelt å spørje om dykkar barn kan delta i nye studiar seinare. Dersom me ynskjer å gjennomføre nye studiar med utgangspunkt i dette materialet, vil de verte informert om hensikta med studien og me vil spørje om nytt samtykke. Ved oppbevaring av data eller gjennomføring av nye studiar etter barnet har fylt 18 år, vil barnet sjølv bli bedt om samtykke.

Frivillig deltaking

Det er frivillig å ta del i studien. Ein kan trekke seg frå prosjektet når som helst og utan å oppgi grunn, og utan at det får negative konsekvensar. Dersom de aksepterer at dykkar barn tek del i studien, underteiknar du samtykkeerklæringa på neste side. Om du seier ja til å vera med no, kan du seinare trekkje tilbake samtykket ditt utan nokon konsekvensar for deg/dykk eller dykkar barn. Dersom du seinare ønskjer å trekke samtykket for dykkar barn eller har spørsmål til studien, ta gjerne kontakt.

Venleg helsing

Eivind Aadland (prosjektleiar), HISF Institutt for Idrett, epost: eivind.aadland@hisf.no; tlf 57676086

Lillian Pedersen, HISF Institutt for Barnehagelærarutdanning, epost: lillian.pedersen@hisf.no ; tlf 57676064

Kjersti Johannessen, HISF Institutt for Idrett, epost: kjerstij@hisf.no; tlf 57676387

Samtykke til deltaking i studien

Eg har lese informasjonsskrivet og aksepterer at mitt barn tek del i studien

----

(Signert av foreldre til prosjektdeltakar, dato)

Barnet sitt førenamn og etternamn: (Skriv tydeleg, helst med blokkbokstavar)

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Foreldre/føresette sitt førenamn og etternamn: (Skriv tydeleg, helst med blokkbokstavar)

………………………………………………………………………………………….

Foreldre/føresette si epost-adresse og mob.tlf nr: (Skriv tydeleg, helst med blokkbokstavar)

………………………………………………………………………………………….

Eg stadfestar at eg har gjeve informasjon om studien

Eivind Aadland 7/4-2015

………………………………………………………………………………………….

(Signert prosjektleiar for studien Eivind Aadland, dato)

APPENDIX V

HØGSKULEN i SOGN OG FJORDANE

Sogn og Fjordane PRESPAS Oppfylging 2016 - 2019

Kjære foreldre/føresette for barn i ein barnehage/skule i Sogndal, Leikanger eller Luster

Sogndal, 5. august 2016

Førespurnad om deltaking i oppfylging til forskingsprosjektet PRESPAS:

Fysisk aktivitet hjå barnehagebarn i Sogn og Fjordane (PRESPAS) Oppfylging 2016 - 2019

De får spørsmål om å delta i dette prosjektet fordi de deltok i prosjektet *Fysisk aktivitet hjå barnehagebarn i Sogn og Fjordane (PRESPAS)* barnehageåret 2015/2016 eller fordi de har barn i ein avdeling i barnehagen eller som går i klasse med barn som tidlegare har teke del i PRESPAS. Prosjektet de no får førespurnad om å ta del i er ei oppfylging av PRESPAS i fire år framover, det vil seie frå **barnehage-/skuleåret 2016/2017 til 2019/2020**. Prosjektet er planlagt å omfatte om lag 400 barn i tre kommunar i Sogn og Fjordane (Sogndal, Leikanger og Luster). **Alle som no får invitasjon er velkomne til å ta del i oppfylginga, uavhengig av tidlegare deltaking**.

Bakgrunn og føremål med prosjektet

Fysisk aktivitet er viktig for barn si normale fysiske, psykiske og sosiale utvikling, men det finnast lite kunnskap om korleis det fysiske aktivitetsnivået utviklar seg over tid hjå barn i Noreg. Tida rundt overgang frå barnehage til skule er ein svært interessant periode å skaffe meir kunnskap om. Føremålet med dette prosjektet er difor å

- Kartlegge utvikling i fysisk aktivitetsnivå hjå 3-8 år gamle barn
- Innhente kunnskap om kva som fremjar fysisk aktivitet hjå barn
- Undersøke samanhengar mellom fysisk aktivitet, motorikk og vektstatus

Kva inneber studien for barnet og for deg/dykk som foreldre/føresette?

Datainnsamlinga vil vere tilsvarande som i PRESPAS, men mindre omfattande. Studien inneber at dykkar barn vil gå med ein aktivitetsmålar i 14 påfølgjande dagar ein gong i året dei fire neste åra. Aktivitetsmålaren skal kun takast av når barnet er i vatn, i tillegg til om natta, men vil elles ikkje påverke barnet sin kvardag. Aktivitetsmålaren blir levert ut og henta inn i barnehagen eller på skulen. Måling av vekt, høgd og motorikk gjerast i samarbeid mellom barnehagen/skulen og prosjektmedarbeidarar. Du/de som foreldre/føresette vil bli spurde om å fylle ut eit kort spørjeskjema med spørsmål om barnet og dykkar ansvarsfordeling for barnet, alder, vekt, høgd, sivil status, utdanning, inntekt og fysisk aktivitet. På to tidspunkt (i 2017 og 2019) vil det også bli gjort ei vurdering av barnet sine motoriske ferdigheiter i kjende rørslemønster som løping, hopping og hinking, samt kast, mottak og spark av ball.

Studien omhandlar:

- Måling av fysisk aktivitetsnivå, motoriske ferdigheiter, vekt og høgd hjå barna
- Kartlegging av fysiske, materielle og sosiale faktorar i skulen
- Innhenting av bakgrunnsinformasjon (kort spørjeskjema) frå foreldre/føresette
- Kopling av desse data med innsamla data gjennom PRESPAS (2015/2016)

Kva skjer med informasjonen om dykk?

Alle data som vert samla inn, både papirbasert og elektronisk, vert handsama i samsvar med krav til personvern og IKT-tryggleik nedfelt i personopplysningslova. Informasjonen som vert registrert om dykkar barn, skal berre nyttast i henhald til føremålet med studien. Alle skjema og data vert avidentifisert, som vil seie at dei vert handsama utan namn og fødselsnummer eller andre direkte opplysningar som kan kople informasjon til dykkar barn. Identifiserbare opplysningar som knyter dykkar barn til opplysningane vert erstatta av ein kode. Lista som koplar kode og namn vert oppbevart på ein sikker måte åtskilt frå forskingsdata, og berre prosjektleiinga har tilgang til namnelista og det er berre dei som kan finne attende til dykkar barn. *Data som vert samla inn vil bli kopla mot data som er samla inn i PRESPAS (2015/2016).*

Høgskulen i Sogn og Fjordane ved dekan på Avdeling for Lærarutdanning og Idrett er databehandlingsansvarleg for studien.

Kva skjer når data er samla inn?

Resultata frå prosjektet vert publisert i form av engelskspråklege artiklar i internasjonal faglitteratur og norske publikasjonar i form av populærvitskaplege artiklar og faglege føredrag. Me understrekar at opplysningar som kjem fram i publikasjonar og føredrag ikkje kan førast tilbake til einskilde personar.

Prosjektet skal vere avslutta innan 2020. Etter dette ynskjer me å oppbevare data for framtidige oppfølgingsstudiar. Det finnes i dag lite kunnskap om langtidseffektar av fysisk aktivitet hjå barn. Difor ynskjer me å kunne gjere nye studiar knytt til korleis fysisk aktivitet kan påverke barn og unge sin oppvekst, læring, livsstil og helse seinare. Datamaterialet og kodelista med namn vert frå 2020 oppbevara hjå Norsk Samfunnsvitenskapelig Datatjeneste fram til 2027. Det kan såleis bli aktuelt å spørje om dykkar barn kan delta i nye studiar seinare. Dersom me ynskjer å gjennomføre nye studiar med utgangspunkt i dette materialet, vil de verte informert om hensikta med studien og me vil spørje om nytt samtykke. Ved oppbevaring av data eller gjennomføring av nye studiar etter barnet har fylt 18 år, vil barnet sjølv bli bedt om samtykke.

Frivillig deltaking

Det er frivillig å ta del i studien. Ein kan trekke seg frå prosjektet når som helst og utan å oppgi grunn, og utan at det får negative konsekvensar. Dersom de aksepterer at dykkar barn tek del i studien, underteiknar du samtykkeerklæringa på neste side. Om du seier ja til å vera med no, kan du seinare trekkje tilbake samtykket ditt utan nokon konsekvensar for deg/dykk eller dykkar barn. Dersom du seinare ynskjer å trekke samtykket for dykkar barn eller har spørsmål til studien, ta gjerne kontakt.

Ta kontakt om de har spørsmål om studien!

Venleg helsing

Eivind Aadland, prosjektleiar, HiSF Institutt for Idrett, epost: eivind.aadland@hisf.no; tlf 57676086

Samtykke til deltaking i studien

Eg har lese informasjonsskrivet og aksepterer at mitt barn tek del i studien

----

(Signert av foreldre til prosjektdeltakar, dato)

Barnet sitt førenamn og etternamn: (Skriv tydeleg, helst med BLOKKBOKSTAVAR)

…………………………………………………………………………………….

Foreldre/føresette sitt førenamn og etternamn: (Skriv tydeleg, helst med BLOKKBOKSTAVAR)

…………………………………………………………………………………….

Foreldre/føresette si adresse, epost-adresse og mob.tlf nr: (Skriv tydeleg, helst med BLOKKBOKSTAVAR)

………..

………..

Eg stadfestar at eg har gjeve informasjon om studien

Eivind Aadland 5/8-2016

……………………………………………………………………………………..

(Signert prosjektleiar for studien Eivind Aadland, dato)

APPENDIX VI

SPØRJESKJEMA TIL FORELDRE/FØRESETTE

Fysisk aktivitet hjå barnehagebarn i Sogn og Fjordane
Denne undersøkinga gjennomførast av Høgskulen i Sogn og Fjordane. Målet er å kartleggje fysisk aktivitetsnivå, og ulike faktorar som kan vere av betydning for fysisk aktivitet hjå 3-6 år gamle barnehagebarn i Sogn og Fjordane.

Informasjonen i dette spørjeskjemaet vert behandla konfidensielt og er kun tilgjengeleg for dei som gjennomfører undersøkinga. Namn vil ikkje gå fram i datafiler eller skriftlig materiale.

Ver venleg å svare så nøyaktig som mogleg på spørsmåla. Set eitt kryss for kvart spørsmål.

Del A kan fyllast ut av ein av foreldra/dei føresette. **Del B** er retta mot barnet si mor/kvinnelege føresette og **Del C** til barnet sin far/mannlege føresette. Dersom begge føresette er av same kjønn, er det fint om de skriv ein kommentar i skjemaet.

Ver merksam på at spørjeskjemaet har spørsmål på begge sider av arket!

VER VENLEG Å LEVERE SPØRJESKJEMAET I BARNEHAGEN SÅ SNART SOM RÅD ETTER AT DE HAR FYLT DET UT.

Ved eventuelle spørsmål, ta kontakt med *Ada Kristine Nilsen (stipendiat)* på epost: ada.kristine.ofrim.nilsen@hisf.no eller tlf: 57676379/91644803, eller *Eivind Aadland (prosjektleiar)* på epost: eivind.aadland@hisf.no eller tlf: 57676086/47623461

PÅ FØREHAND TAKK FOR HJELPA!

DEL A - BARNET

Denne delen kan fyllast ut av kven som helst av foreldra/føresette. Skriv svaret på den stipla lina eller set eit kryss i den ruta de meiner passar best.

1. **Kva er namnet til barnet** …………………………………………………………….

2. **Kva er fødselsdato til barnet?** ……………………… (treng ikkje personnummer)

3. **Kva var fødselsvekta til barnet dykkar?** ………………… gram.

4. **Har barnet dykkar ein lang sjukdomsperiode, kronisk sjukdom eller anna medisinsk problem no, eller har barnet hatt dette tidlegare?**

   ☐ Ja
   ☐ Nei

   Dersom svaret er JA, ver venleg å gi ein kort beskrivelse:

   ……

   ……

5. **Kvar er barnet og de som foreldre/føresette født?**

Barn: ☐ Noreg ☐ Anna stad (skriv kvar): …………………………………………..
Mor: ☐ Noreg ☐ Anna stad (skriv kvar): …………………………………………..
Far: ☐ Noreg ☐ Anna stad (skriv kvar): …………………………………………..

6. **Kor mange søsken har barnet?** ………..

7. **Korleis kjem de dykk til og frå barnehagen som oftast?**

   ☐ Barnet går
   ☐ Barnet syklar, brukar sparkesykkel eller liknande
   ☐ Køyrer bil eller blir transportert på annan måte
   ☐ Nyttar offentleg transport

8. **Deltek barnet i organisert idrett/fysisk aktivitet?**

   ☐ Ja
   ☐ Nei

Dersom ja; kva type (barneidrett, turn, ski..)? ……………………………………………………

DEL B – MOR/KVINNELEG FØRESETT

Denne delen inneheld spørsmål til <u>barnet si mor</u> (eller kvinnelige føresette).
Skriv svaret på den stipla lina eller set eit kryss i den ruta du meiner passar best.

1. **Kva er ditt fødselsår?** …………………

2. **Kor høg er du?** ………………… (cm)

3. **Kva veg du?** ………………… (kg)

4. **Har du ansvaret for barnet åleine?**
☐ Ja
☐ Nei

5. **Kva sivil status har du?**
☐ Gift/sambuar
☐ Åleine (inkludert enke, fråskilt)

6. **Kva er ditt høgste fullførte utdanningsnivå?**
☐ Grunnskule
☐ Vidaregåande skule
☐ Høgskule eller universitet, gi opp kor mange år ……………

7. **Kva er årsinntekta di (i tusen kroner)?**
☐ under 100 ☐ 100 – 200 ☐ 200 – 300 ☐ 300 – 400 ☐ 400 – 500
☐ 500 – 600 ☐ 600 – 700 ☐ 700 – 800 ☐ 800 – 900 ☐ over 900

Når du svarer på spørsmåla 8 - 11:

Meget anstrengande – er fysisk aktivitet som får deg til å puste *mykje meir* enn vanleg
Middels anstrengande – er fysisk aktivitet som får deg til å puste *litt meir* enn vanleg

Det er kun aktivitetar som varer **minst 10 minutt i strekk** som skal rapporterast

8.a) **Kor mange dagar i løpet av dei siste 7 dagane har du drive med *<u>meget anstrengande</u>* fysiske aktivitetar som tunge løft, gravearbeid, aerobics eller å sykla fort?** Tenk bare på aktivitetar som varer *minst 10 minutt i strekk*

☐ Dagar per veke ☐ Ingen (gå til spørsmål 9.a)

8.b) **På ein vanlig dag der du utførte *<u>meget anstrengande</u>* fysiske aktivitetar, kor lang tid brukte du då på dette?**

☐ Timar ☐ Minutt ☐ Veit ikkje/hugsar ikkje

9.a) Kor mange dagar i løpet av dei siste 7 dagane har du drive med *middels anstrengande* fysiske aktivitetar som å bere lette ting, sykla eller jogga i moderat tempo eller mosjonstennis? Ikkje ta med gange, det kjem i neste spørsmål.

☐ Dagar per veke ☐ Ingen (gå til spørsmål 10.a)

9.b) På ein vanleg dag der du utførte *middels anstrengande* fysiske aktivitetar, kor lang tid brukte du då på dette?

☐ Timar ☐ Minutt ☐ Veit ikkje/hugsar ikkje

10.a) Kor mange dagar i løpet av dei siste 7 dagane, *gjekk du minst 10 minutt* i strekk for å kome deg frå ein stad til ein annan? Dette inkluderer gange på jobb og heime, gange til buss, eller gange som du gjer på tur eller som trening i fritida

☐ Dagar per veke ☐ Ingen (gå til spørsmål 11)

10.b) På ein vanleg dag der du *gjekk* for å komme deg frå ein stad til ein annan, kor lang tid brukte du då totalt på å gå?

☐ Timar ☐ Minutt ☐ Veit ikkje/hugsar ikkje

11. Dette spørsmålet omfattar all tid du brukar *sittande* på jobb, heime, på kurs, og på fritida. Det kan vere tida du sit ved et arbeidsbord, hjå vener, mens du les eller ligg for å sjå på TV.

I løpet av dei siste 7 dagane, kor lang tid brukte du vanligvis totalt på å *sitta* på ein vanlig kvardag?

☐ Timer ☐ Minutt ☐ Veit ikkje/hugsar ikkje

TAKK FOR AT DU HAR SVARA PÅ SPØRJESKJEMAET!

DEL C – FAR/MANNLEG FØRESETT

Denne delen inneheld spørsmål til <u>barnet sin far</u> (eller mannlege føresette).
Skriv svaret på den stipla lina eller set eit kryss i den ruta du meiner passar best.

1. **Kva er ditt fødselsår?** …………………

2. **Kor høg er du?** ………………… (cm)

3. **Kva veg du?** ………………… (kg)

4. **Har du ansvaret for barnet åleine?**
   ☐ Ja
   ☐ Nei

5. **Kva sivil status har du?**
   ☐ Gift/sambuar
   ☐ Åleine (inkludert enke, fråskilt)

6. **Kva er ditt høgste fullførte utdanningsnivå?**
   ☐ Grunnskule
   ☐ Vidaregåande skule
   ☐ Høgskule eller universitet, gi opp kor mange år ……………

7. **Kva er årsinntekta di (i tusen kroner)?**
   ☐ under 100 ☐ 100 – 200 ☐ 200 – 300 ☐ 300 – 400 ☐ 400 – 500
   ☐ 500 – 600 ☐ 600 – 700 ☐ 700 – 800 ☐ 800 – 900 ☐ over 900

Når du svarer på spørsmåla 8 - 11:

Meget anstrengande – er fysisk aktivitet som får deg til å puste *mykje meir* enn vanleg
Middels anstrengande – er fysisk aktivitet som får deg til å puste *litt meir* enn vanleg

Det er kun aktivitetar som varer **minst 10 minutt i strekk** som skal rapporterast

8.a) Kor mange dagar i løpet av dei siste 7 dagane har du drive med *<u>meget anstrengande</u>* fysiske aktivitetar som tunge løft, gravearbeid, aerobics eller å sykla fort? Tenk bare på aktivitetar som varer *minst 10 minutt i strekk*

☐ Dagar per veke ☐ Ingen (gå til spørsmål 9.a)

8.b) På ein vanlig dag der du utførte *<u>meget anstrengande</u>* fysiske aktivitetar, kor lang tid brukte du då på dette?

☐☐ Timar ☐☐ Minutt ☐ Veit ikkje/hugsar ikkje

9.a) Kor mange dagar i løpet av dei siste 7 dagane har du drive med *middels anstrengande* fysiske aktivitetar som å bere lette ting, sykla eller jogga i moderat tempo eller mosjonstennis? Ikkje ta med gange, det kjem i neste spørsmål.

☐ Dagar per veke ☐ Ingen (gå til spørsmål 10.a)

9.b) På ein vanleg dag der du utførte *middels anstrengande* fysiske aktivitetar, kor lang tid brukte du då på dette?

☐ Timar ☐ Minutt ☐ Veit ikkje/hugsar ikkje

10.a) Kor mange dagar i løpet av dei siste 7 dagane, *gjekk du minst 10 minutt* i strekk for å kome deg frå ein stad til ein annan? Dette inkluderer gange på jobb og heime, gange til buss, eller gange som du gjer på tur eller som trening i fritida

☐ Dagar per veke ☐ Ingen (gå til spørsmål 11)

10.b) På ein vanleg dag der du *gjekk* for å komme deg frå ein stad til ein annan, kor lang tid brukte du då totalt på å gå?

☐ Timar ☐ Minutt ☐ Veit ikkje/hugsar ikkje

11. Dette spørsmålet omfattar all tid du brukar *sittande* på jobb, heime, på kurs, og på fritida. Det kan vere tida du sit ved et arbeidsbord, hjå vener, mens du les eller ligg for å sjå på TV.

I løpet av dei siste 7 dagane, kor lang tid brukte du vanligvis totalt på å *sitta* på ein vanlig kvardag?

☐ Timer ☐ Minutt ☐ Veit ikkje/hugsar ikkje

TAKK FOR AT DU HAR SVARA PÅ SPØRJESKJEMAET!

APPENDIX VII

Sogn og Fjordane PRESPAS

Fysisk aktivitet hjå barnehagebarn

TEST AV MOTORISKE FERDIGHETER – SKÅRINGSSKJEMA

Dato:____________ Barnehage:____________________________ Avdeling:______________________

Instruktør:______________________ Scorer:__________________________

#1. Navn:______________________________ #2. Navn:______________________________

#3. Navn:______________________________ #4. Navn:______________________________

Navn/initialer	**#1**		**#2**		**#3**		**#4**	
Vurderingskriterier: LØP	**T1**	**T2**	**T1**	**T2**	**T1**	**T2**	**T1**	**T2**
Arm svinger synkront med motsatt bein med bøyde albuer								
Smal beinstilling, barnet lander på helen eller tærne (ingen stamping/landing på flat fot)								
Korte perioder hvor begge føttene er i luften/svevfase forekommer								
Kneet på beinet som ikke er i kontakt med bakken bøyes (ca 90 grader/ foten kommer nær baken)								

Vurderingskriterier: HOPP	**T1**	**T2**	**T1**	**T2**	**T1**	**T2**	**T1**	**T2**
Armene strekes kraftfullt frem og opp over hodet når barnet hopper								
Før føttene forlater underlaget er begge knærne bøyd og armene strukket bak ryggen								
Begge føttene forlater gulvet samtidig og lander samtidig								
Begge armene beveger seg nedover under «landingen»								
Lengde (cm)								

Vurderingskriterier: HINKE	**T1**	**T2**	**T1**	**T2**	**T1**	**T2**	**T1**	**T2**
Beinet som er i luften svinger fremover med pendelbevegelse for å skape kraft								
Foten på beinet som er i luften holdes bak beinet barnet hopper med (krysser ikke foran)								
Armene bøyes og svinges fremover for å skape kraft								
Barnet hinker fire ganger sammenhengende på samme bein før han/hun stopper								

Vurderingskriterier: MOTTAK	**T1**	**T2**	**T1**	**T2**	**T1**	**T2**	**T1**	**T2**
Barnets hender er posisjonert foran kroppen med bøyde albuer								
Armene strekkes mot ballen når den kommer mot barnet								
Ballen tas imot kun med hendene								

Navn/initialer	**#1**		**#2**		**#3**		**#4**	
Vurderingskriterier: OVERARMSKAST	**T1**	**T2**	**T1**	**T2**	**T1**	**T2**	**T1**	**T2**
Tar et steg mot veggen med motsatt fot til kast-arm								
Hofte og skulder roterer slik at skulderen på den passive armen vinkles mot veggen								
I siste fase av kastet føres hånden og armen nedover								
Kast-arm følger bevegelsen videre etter ballen, og krysser foran kroppen mot hoften på motsatt side								

Vurderingskriterier: SPARK PÅ BALL	**T1**	**T2**	**T1**	**T2**	**T1**	**T2**	**T1**	**T2**
Rask, kontinuerlig bevegelse mot ballen								
Foten som ikke sparker plasseres nær ballen								
Barnet sparker ballen med innsiden av foten eller vrista (ikke tærne)								

Vurderingskriterier: BALANSERE PÅ EN FOT	**T1**	**T2**	**T1**	**T2**	**T1**	**T2**	**T1**	**T2**
Begge hender forblir på hoften								
De to bena lenes ikke mot hverandre								
Benet barnet ikke står på er bøyd i kneet og rettet ut i hoften.								
Barnet klarer å stå i ro på en fot i 5 sekunder								

Vurderingskriterier: GÅ PÅ LINJE BAKLENGS	**T1**	**T2**	**T1**	**T2**	**T1**	**T2**	**T1**	**T2**
Begge føttene er i kontakt med linje								
Veiver ikke med armene for å holde balansen								
Hvert skritt går bak det forrige								
Går baklengs med oppreist posisjon - minimum seks skritt								

Vurderingskriterier: GÅ PÅ LINJE FOROVER	**T1**	**T2**	**T1**	**T2**	**T1**	**T2**	**T1**	**T2**
Begge føttene er i kontakt med linjen								
Veiver ikke med armene for å holde balansen								
Går på linjen på hele strekningen								
Kontinuerlig hel-til-tå gange minimum seks skritt								

Kommentarer til gjennomføring:

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