DISSERTATION FROM THE
NORWEGIAN SCHOOL OF
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Knut Eirik Dalene

Physical activity in Norwegian children and adolescents

With a special focus on physical activity trends, health implications, correlates and determinants of physical activity

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Sammendrag på norsk

Innledning: For å kunne gjøre nøyaktige vurderinger av barn og unges fysiske aktivitetsnivå, og hvordan dette endres over tid, trenger vi populasjonsbaserte studier hvor fysisk aktivitet måles ved hjelp av objektive, reliable og valide metoder. Dette er essensielt for å informere folkehelsepolitikken, og for øke kunnskapen om tidsavhengige og aldersrelaterte endringer i fysisk aktivitet. Videre er det viktig for å øke kunnskapen om forholdet mellom fysisk aktivitet og helse hos barn og unge. I tillegg er økt kunnskap om faktorer som påvirker barn og unges fysiske aktivitetsnivå essensiell for utarbeidelsen av fremtidige aktivitetsfremmende tiltak.

Hensikten med avhandlingen: Hensikten med denne avhandlinger var: **I)** å undersøke sekulære og longitudinelle endringer i fysisk aktivitet; **II)** å undersøke sammenhengen mellom fysisk aktivitet og fedme, og; **III)** å undersøke korrelater og determinanter for fysisk aktivitet.

Metode: Denne avhandlinger er basert på data fra to nasjonale kartleggingsundersøkelser av fysisk aktivitetsnivå hos norske barn og unge (ungKan). ungKan1 ble gjennomført i 2005/06 og inkluderte populasjonsbaserte utvalg av 9- og 15-åringer (n=2229). ungKan2 ble gjennomført i 2011/12 og inkluderte populasjonsbaserte utvalg av 6-, 9- og 15-åringer (n=3598), hvorav 731 av 15-åringene tidligere hadde deltatt i ungKan1 da de var ni år gamle. Fysisk aktivitet ble målt objektivt ved hjelp av akselerometre i begge undersøkelsene.

Hovedresultater: I) Andelen av 9- og 15-åringer som tilfredsstilte de norske anbefalingene for fysisk aktivitet (60 minutter fysisk aktivitet med minst moderat intensitet daglig) var ikke forskjellig i 2005/06 og 2011/12, men både 9- og 15-åringer brukte mer tid stillesittende og mindre tid i lett fysisk aktivitet i 2011/12 sammenlignet med 2005/06. **I)** Det gjennomsnittlige aktivitetsnivået til både jenter og gutter gikk ned med >30% fra ni til 15 år. **II)** Utskifting av stillesittende tid med tid brukt i aktivitet med minst moderat intensitet var inverst assosiert med fedme hos barn. Hos ungdom ble det kun observert gunstige assosiasjoner når det ble modellert en utskifting av stillesittende tid med hard fysisk aktivitet. Utskifting av stillesittende tid med tid i fysisk aktivitet av ulike intensiteter ved ni år var ikke assosiert med fedme ved 15 år. **III)** Verken antallet permanente lekefasiliteter i skolens uteområde eller størrelsen på skolens uteområde ser ut til å være sterke korrelater for fysisk aktivitet i Norge. **III)** Aktiv skoletransport (gå eller sykle) og deltakelse i idretts- eller treningsaktiviteter var gunstig assosiert med tid brukt i moderat-til-hard fysisk aktivitet på ukedager. Moderat-til-hard fysisk aktivitet på ukedager ser ikke ut til å være assosiert med søvnlengde, og er kun svakt assosiert med skjermtid. Verken søvnlengde, skjermtid, aktiv skoletransport eller deltakelse i idretts- eller treningsaktiviteter ved ni år predikerte tid brukt i moderat-til-hard fysisk aktivitet ved 15 år.

Konklusjon: Tiltak for å øke fysisk aktivitet gjennomført siden midten av 2000-tallet har ikke hatt tilstrekkelig effekt til å øke norske barns fysiske aktivitetsnivå. Gitt de mange gunstige effektene fysisk aktivitet gir barn og unge, og det store fallet i fysisk aktivitet fra barne- til ungdomsårene, bør tiltak for å øke fysisk aktivitet blant barn og unge derfor gis økt prioritet i tiden fremover. Våre funn indikerer at en relativt liten økning i fysisk aktivitet av moderat og/eller hard intensitet kan ha gunstige effekter på barn og unges kroppssammensetning. Til slutt indikerer våre funn at folkehelseintervensjoner som ønsker å øke fysisk aktivitet hos barn og unge bør øke mulighetene for aktiv skoletransport og deltakelse i idretts- eller treningsaktiviteter.

Stikkord: Barn, ungdom, fysisk aktivitet, stillesittende tid, kroppsmasseindeks, midjeomkrets, fedme, korrelater, determinanter, søvn, skjermtid, aktiv transport, idrett, trening, skole, akselerometer, epidemiologi, tverrsnitt, prospektiv, longitudinell, isotemporal.

Summary

Introduction: In order to accurately assess the physical activity levels of children and adolescents and how it changes over time, there is a continuing need for population-based studies quantifying physical activity using objective, reliable, and valid methods. This is essential to inform public health policy and to provide information about time-dependent and age-related changes in physical activity. Furthermore, it is important to increase knowledge about the relationship between physical activity and potential implications to health. In addition, insight regarding correlates and determinants of physical activity is integral for the development of future physical activity-promoting interventions.

Purpose: The main objectives of this research were: **I)** to investigate secular and longitudinal changes in physical activity; **II)** to investigate the association between physical activity and markers of adiposity, and; **III)** to investigate physical activity correlates and determinants.

Participants and methods: This thesis is based on the first and second wave of the Physical Activity among Norwegian Children study (PANCS). PANCS1 was conducted in 2005/06 and included population-based samples of 9- and 15-year olds (n = 2,299). PANCS2 was conducted in 2011/12 and included population-based samples of 6-, 9- and 15-year olds (n = 3,598), of which 731 15-year olds had previously participated in PANCS1 at age nine. Physical activity was assessed objectively by accelerometry in both study waves.

Main results: I) The proportions of 9- and 15-year olds adhering to the Norwegian physical activity recommendations did not change between 2005/06 and 2011/12, but both 9- and 15-year olds spent more time sedentary and less time in light physical activity in 2011/12 compared to 2005/06. **I)** Both girls and boys decreased their overall physical activity level by > 30% from age nine to 15 years. **II)** Theoretical substitution of sedentary time with moderate and vigorous physical activity was favorably associated with adiposity in children. In adolescents, favorable associations were only observed when sedentary time was substituted with vigorous physical activity. Substitution of sedentary time with physical activity at age nine was not associated with adiposity at age 15. **III)** The number of permanent play facilities and the size of schools' outdoor play areas do not seem to be strong environmental correlates of physical activity in Norway. **III)** Active school transport and participation in sport or exercise activities was favorably associated with moderate-to-vigorous physical activity (MVPA) on weekdays. Moderate-to-vigorous physical activity on weekdays does not seem associated with sleep duration and only weakly associated with screen time. Sleep duration, screen time, active school transport, and sports or exercise participation at age nine did not predict MVPA at age 15.

Conclusions: Because of the ample evidence of the beneficial health effects of physical activity, the lack of improvement in the physical activity levels of children and adolescents since the mid-2000s, and the large declines in physical activity observed from childhood to adolescence, efforts to increase children's and adolescents' physical activity levels should be given higher priority in coming years. Based on our results, it seems that small daily reallocations of time spent sedentary to physical activity of moderate and/or vigorous intensity may favorably affect the body composition of children and adolescents. Lastly, our results suggest that public health interventions aiming to increase physical activity in children and adolescents should include opportunities for active school transport and participation in sport and exercise activities.

Keywords: Children, adolescents, physical activity, sedentary, body mass index, waist circumference, adiposity, correlates, determinants, sleep, screen time, active transport, sport, exercise, school, accelerometer, epidemiology, cross-sectional, prospective, longitudinal, isotemporal.

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Oslo, February 2018

Knut Eirik Dalene

Abbreviations

BMI:	Body mass index
LPA:	Light physical activity
MET:	Metabolic equivalent of task
MPA:	Moderate physical activity
MVPA:	Moderate-to-vigorous physical activity
ST:	Sedentary time
VPA:	Vigorous physical activity
WC:	Waist circumference

List of papers

This dissertation is based on the following original research papers, which are referred to in the text by their Roman numerals:

I. Dalene, K. E., Anderssen, S. A., Andersen, L. B., Steene-Johannessen, J., Ekelund, U.,Hansen, B. H., & Kolle, E. (2018). *Secular and longitudinal physical activity changes in population-based samples of children and adolescents.* Scand J Med Sci Sports. 2018;28:161–171. doi: 10.1111/sms.12876

II. Dalene, K. E., Anderssen, S. A., Andersen, L. B., Steene-Johannessen, J., Ekelund, U., Hansen, B. H., & Kolle, E. (2017). *Cross-sectional and prospective associations between physical activity, body mass index and waist circumference in children and adolescents.* Obes Sci Pract. 2017 Jun 8;3(3):249-257. doi: 10.1002/osp4.114.

III. Dalene, K. E., Anderssen, S. A., Ekelund, U., Thorén, A.-K. H., Hansen, B. H., & Kolle, E. (2016). *Permanent play facility provision is associated with children's time spent sedentary and in light physical activity during school hours: A cross-sectional study.* Preventive Medicine Reports, 4, 429-434. doi: 10.1016/j.pmedr.2016.08.011

IV. Dalene, K. E., Anderssen, S. A., Andersen, L. B., Steene-Johannessen, J., Ekelund, U., Hansen, B. H., & Kolle, E. (2017). *Cross-sectional and prospective associations between sleep duration, screen time, active school travel, sports/exercise participation and habitual physical activity in children and adolescents.* Submitted.

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1. Introduction

Although advocated as a health enhancing endeavor already in ancient Greece [1], there is general consensus that the first proper scientific findings of a link between physical activity (PA) and disease risk arose with the London Transport Workers Study conducted in the 1950s [2, 3]. Since then, the PA and health research field has grown tremendously and it is now widely accepted that physical inactivity increases the risk of several non-communicable diseases and all-cause mortality [4, 5]. Furthermore, conservative estimates show that physical inactivity causes more than five million premature deaths every year and costs health-care systems 53.8 billion international dollars worldwide in 2013 [6, 7].

Non-communicable diseases rarely manifest during childhood. The difficulty, therefore, is linking physical inactivity to hard clinical endpoints, such as cardiovascular disease and premature mortality, in children and adolescents. However, convincing evidence has emerged of a pronounced association between low levels of PA and an adverse metabolic profile already at a young age [8-10]. Therefore, it has become a global priority to increase PA in children and adolescents [11].

Despite this, little is known regarding how the PA levels of children and adolescents have changed over time, and scholarly understanding of the factors associated with PA remains limited. Consequently, in order to develop successful PA-promoting strategies accurate and representative data on PA, its correlates, and determinants are needed. The focus of this thesis lies therefore on exploring secular trends in the PA level of children and adolescents and on investigating factors associated with PA, using objectively assessed PA data from two large population-based samples of children and adolescents.

1.1 Definitions and basic principles of physical activity

1.1.1 Physical activity

Physical activity is commonly defined as *any bodily movement produced by skeletal muscles that results in energy expenditure* [12]. Physical activity is a highly complex and multidimensional behavior, spanning from the most basic forms of human movement to protracted exercise or labor with very high energy costs. Dimensions of PA include *duration* (units of time), *frequency* (number of sessions per time unit), and *intensity*, which together make up the *total volume* of the PA (*duration* x *frequency* x *intensity*). *Mode* (or type) and *domain* are other important dimensions of PA. *Mode* refers to the different physical activities a person engages in (e.g. running, bicycling, climbing, gardening) and *domain* to the context or reason for the PA (e.g. playground, physical education class, transportation).

Referring to multiples of the resting metabolic rate (RMR), researchers often use metabolic equivalent of task (MET) values to describe the intensity of different physical activities. For adults, the resting metabolic rate, or one MET, is equal to an oxygen uptake (VO_2) of ~3.5 $ml \cdot kg^{-1} \cdot min^{-1}$ or ~1 $kcal \cdot kg^{-1} \cdot h^{-1}$ [13]. The MET values of more than 800 specific activities have been described, ranging from 0.9 (sleeping) to 23 (running at 22.5 $km \cdot h^{-1}$) [14]. Physical activity is most often considered to be of light, moderate, or vigorous intensity if its associated energy cost lies between 1.5-2.9 METs, 3.0-5.9 METs and ≥6.0 METs, respectively [14]. The energy expenditure from PA usually makes up 20-30% of a person's total daily energy expenditure, but can make up as much as 80% in individuals with extremely high PA levels [15].

1.1.2 Sedentary behavior and sedentary time

In recent years, there has been a rapid and progressive growth in the number of studies investigating potential links between sedentary behavior and adverse health indicators or outcomes [16]. Sedentary behavior is defined as *any waking behavior characterized by an energy expenditure ≤1.5 METs, while in a sitting, reclining or lying posture* [17]. The term "sedentary behavior" is often used interchangeably with "sedentary time". However, a recent terminology consensus project conducted by the Sedentary Behavior Research Network (SBRN) concluded that, although the terms overlap, sedentary time is distinct from sedentary behavior and should be defined as *the time spent for any duration (e.g., minutes per day) or in any context (e.g., at school or work) in sedentary behaviors* [18]. Thus, both definitions have dual components, including both energy expenditure and posture, but sedentary behavior can only be assessed if the context (domain) of the behavior is known.

The term *sedentary* is often used interchangeably with *inactive* and *physically inactive* in the literature. However, physical inactivity is defined as an insufficient PA level to meet present PA recommendations [18]. Because PA recommendations can be met even if large proportions of the day are spent sedentary, this interchangeable use of terms is misleading and should be avoided [17].

1.2 Physical activity in children and adolescents

Children and adults have PA patterns that differ substantially [19]. Direct observation of free-living PA in 6-to-10-year-old children in a variety of settings has shown the median durations of light-to-moderate (2-7 METs) and high-intensity (≥ 7 METs) activities to be 6 and 3 seconds, respectively, with 95% of high intensity activities lasting less than 15 seconds [20]. Furthermore, 75% of observed intervals between high-intensity activity events lasted only ≤ 54 seconds, illustrating the intermittent and spontaneous nature of children's PA. Although PA patterns of adolescents gradually become more similar to those of adults, it is likely that substantial differences continue to exist, e.g. through engagement in higher levels of active transportation (e.g. walking, cycling, or skate boarding), sports (organized or unorganized), physical education, and PA during school recess periods [21].

1.2.1 Physical activity recommendations

Intended to identify the minimum amount of PA required for good health, PA recommendations for children were first introduced by the American College of Sports Medicine in 1988 [22]. Based primarily on expert opinions, the recommendations suggested that *children and youth should obtain 20-30 minutes of vigorous exercise each day*. Over the next decade, the amount of research on PA and health in children grew substantially, and in 1998, the Health Education Authority in the UK initiated a revision of the recommendations. Based on eight literature reviews and expert opinions from more than 50 international academics and experts, the new recommendations stated that *all young people should participate in physical activity of at least moderate intensity for 1 hour per day* [23]. Further, they stated that *at least twice a week, some of these activities should help to enhance and maintain muscular strength, flexibility and bone health*. Since then, new evidence has emerged that provides further justification for these recommendations [24] and today the World Health Organization (WHO) and many countries around the world advocate recommendations similar to the 1998 recommendations [4, 25]. It should however be noted that some countries recommend more and some less than 60 min/d of MVPA [25]. Others have developed 24h movement guidelines including recommendations for sleep and screen time [26].

In Norway, PA recommendations for children were first presented in 2000 [27]. These were revised in 2014 [28] and now state: 1) *Children and adolescents should engage in at least 60 minutes of physical activity each day. The physical activity should be of moderate-to-vigorous intensity. At least three times per week, physical* *activity of vigorous intensity that increases muscle- and bone strength should be implemented.* 2) *Physical activity in excess of 60 minutes per day gives additional health benefits.* 3) *Reduce sedentary behavior.*

1.3 Assessment of physical activity

To draw meaningful conclusions about PA, either as an exposure, outcome, or covariate, valid, reliable, and feasible assessment methods are required [29]. Precise methods of assessment are necessary to accurately establish the dose-response relationship between PA and various health outcomes, to monitor the effect of PA interventions, to determine temporal trends in PA, and to make cross-cultural comparisons of PA [30]. Currently, no single assessment method is able to capture all dimensions of free-living PA and certain research questions may therefore require a combination of methods. Numerous PA assessment methods exist, which can broadly be categorized as either subjective (e.g. questionnaires and diaries) or objective (e.g. direct observation, calorimetry, heart-rate monitors, and motion sensors) [31]. There are advantages and disadvantages to each of the available methods that should be considered before deciding on which instrument to use. Table 1 summarizes the advantages and disadvantages of methods used to assess free-living PA.

Table 1. Ranking of methods for the assessment of habitual PA on six different parameters, where 1 denotes the highest and 5 the lowest rank. Adapted from Westerterp [32].

	Subject interference	**Subject effort**	**Contextual information**	**Activity structure**	**Objective data**	**Observer time/cost**
Behavioral observation	5	1	1	2	4	5
Self-report*	4	5	2	4	5	2
Heart-rate monitoring	3	4	4	3	3	3
Motion sensors	2	3	3	1	2	1
Doubly labeled water**	1	2	5	5	1	4

*Questionnaires, diaries, interviews. **Indirect calorimetry

1.3.1 Subjective methods

Traditionally, pragmatic considerations have often led to the use of subjective methods as the tool of choice for PA assessment in children. Particularly in large-scale epidemiological studies, budget, resources, and staff availability used to exclude the use of objective methods [33]. Subjective methods include self- and interview administered questionnaires, diaries and logs, and proxy reports from parents or teachers. Questionnaires are the most common subjective method used, because researchers often regard diaries and logs as too burdensome for the participants and proxy reports as too imprecise, since parents and teachers are unable to observe children continuously for several days.

burden, the potential reactivity of the study participants, and the impossible task of observing and coding all waking time over several days.

Doubly labeled water

The DLW technique is the other method regarded as a "golden standard" for free-living PA assessment. The DLW technique was first introduced for humans in 1982 and involves ingestion of water labeled with the stable isotopes H_2 and ^{18}O [43]. After ingestion, H_2 is eliminated from the body as water, while ^{18}O is eliminated as both water and CO_2. Therefore, the difference between the rates of elimination of H_2 and O^{18} can be used to precisely and accurately measure CO_2 production [15]. Combined with information on macronutrient intake, the CO_2 production can be used to calculate total energy expenditure (TEE) accurately over 0.5 to 4 weeks, depending on the sampling protocol and the characteristics of the subjects under study [15, 44].

To compare the PA level (PAL) within and between subjects, total energy expenditure is often divided by basal metabolic rate (BMR) to create a figure without dimension: PAL = TEE/BMR [45]. This value can be used to classify subjects as having a sedentary or light active life style (PAL 1.40-1.69), a moderately active or active lifestyle (PAL 1.70-1.99), or a vigorously active lifestyle (PAL 2.00-2.40) [46]. Another frequently used measure of PA from the DLW technique is PA-induced energy expenditure (PAEE). Because diet-induced energy expenditure is ~10% of TEE in subjects consuming the average mixed diet while being in energy balance [47], PAEE can be calculated as: *PAEE = 0.9*TEE–BMR* [15]. Physical activity induced energy expenditure is thus an estimate of a person's overall PA level, usually presented as average kcals or kJs per day.

Although the DLW technique gives no information on the frequency, intensity, duration, mode, or domain of PA, studies investigating the validity of other PA assessment methods regularly use the DLW technique as a criterion method. However, even if it is the best available assessment method of unrestrained, free-living PAEE, the DLW technique has obvious drawbacks that make it unsuitable in large-scale studies. First, the stable isotopes used are very costly. Second, the mass spectrometry analysis used to estimate PAEE from samples of body fluid, blood, saliva, or urine is highly sophisticated. Third, increased accuracy of the TEE and PAEE estimates requires that participants carefully register food intake. Lastly, accurate estimation of PAEE requires measurement of BMR in the laboratory using a stringent protocol.

Pedometers

Pedometry has been a long-standing objective assessment method of ambulatory PA (steps) [48]. Whereas early pedometers consisted of gear-driven mechanical systems, most modern devices are electronic, consisting of a spring-suspended horizontal lever arm that moves with the vertical acceleration of the hip during ambulation [49]. The spring-suspended lever arm makes an electronic contact or compresses a piezoelectric crystal, causing an electrical circuit to open and close with each deflection detected. The pedometer records each electronic impulse generated as a step [48, 50].

The accuracy and reliability of numerous different pedometers has been investigated, and several monitors provide step counts very close to step counts measured by direct observation (±1%) [51]. The accuracy does, however, decline at slower walking speeds [50]. Further, the intra- (Cronbach's $\alpha > 0.99$) and inter-monitor (ICC 0.73-0.96) reliability for step counts of several models are high [52, 53] and correlations between pedometer step counts and VO_2 during treadmill locomotion is moderate to high in children ($r = 0.62$ to 0.93) [31]. However, energy expenditure estimated from pedometry under free-living conditions remains much more questionable and sometimes values have been underestimated by as much as 30–60% relative to DLW estimates [30, 48]. This can be attributed to pedometers' poor response to cycling, skating, load-carrying, and other non-ambulatory activities and to the fact that they do not account for the additional cost of climbing hills or making movements against external resistance [48]. Although some pedometers store step counts in time stamped epochs, such that cadence (i.e. steps/minute) can be used as a proxy measure of intensity [54, 55], most pedometers cannot quantify intensity, duration, or frequency of activity bouts. Nevertheless, pedometry is objective, cheap, unobtrusive, and can be used in large-scale studies to assess ambulatory PA in children and adolescents [56] or in any situation where only a measure of total ambulatory activity and not activity pattern is required [57].

Heart-rate monitors

Heart-rate monitoring was the first widely used objective assessment method of PA in children [57]. Heart-rate monitors are socially acceptable, permit freedom of movement, and are not immediately noticeable, so they should not unduly influence the child's normal activity pattern [58]. Although heart-rate monitoring does not provide a direct measure of PA, it provides an indication of the relative cardiopulmonary stress caused by PA [57]. Heart-rate monitors also provide time stamped data, facilitating the quantification of intensity, duration, or frequency of PA bouts.

Numerous methods of analyzing heart rate activity data have been used [59], most of which are based on the assumption of a linear relationship between heart rate and oxygen consumption in MVPA [60]. Although TEE and PAEE estimated from heart rate show reasonable agreement with measured TEE (DLW) and PAEE (spirometry-based indirect calorimetry) in children at the group level [61-63], the labor-intensive nature of the individual calibration needed to increase accuracy hampers feasibility for large-scale studies [58]. Most studies assessing free-living PA in children have therefore used time spent above certain heart-rate thresholds as equivalent to MVPA, either arbitrary thresholds (e.g. 120 or 140 beats per minute) or thresholds based on some form of heart rate:VO_2 (MET) calibration [30]. Because many factors other than PA can influence heart rate, e.g. emotional stress, anxiety, level of fitness, type of muscular contraction, active muscle group, hydration, and environment, heart-rate monitoring is not a recommended method for assessing PA of light intensity [57].

Accelerometers

Accelerometers are small wearable monitors that record accelerations (m/s^2) in gravitational units (g) in one or more planes. The accelerations are sampled at rates > 1 time/second (typically 10–100 Hz) and are then often processed to a lower resolution (i.e., epoch) and calibrated against criterion measures (e.g., indirect calorimetry) [34]. Because PA involves changes in the position of body segments resulting from skeletal muscle contractions, a measure of acceleration of the body or its segments can be used to infer intensity of PA over time, allowing derivation of activity dimensions such as duration, frequency, and overall volume [64].

The application of accelerometry in the PA research field has grown tremendously over the last 20 years, and many now regard accelerometry as the method of choice for assessing PA in large-scale studies [65]. The method has even been used to assess PA in epidemiological studies with thousands of participants [66-71].

Although the use of raw acceleration data to facilitate comparison of data collected with different accelerometer brands has been advocated in recent years [72], the vast majority of studies still choose to convert the raw data to brand-specific "activity counts". Because these count values are proportional to the amplitude and frequency of acceleration, the number of counts registered per time unit can be used to describe PA levels and time spent in PA of different intensities. The average number of counts registered per minute over an assessment period (e.g. 4-7 days) is often used as a measure of the participants' overall PA level. Further, the number of counts registered within user defined time intervals (epochs) are used to assess time spent with an activity level above or below count thresholds equivalent to sedentary, light, moderate, and vigorous intensity. Such count thresholds, or "cut-points", also facilitate the assessment of PA patterns and of time spent in prolonged sedentary or physically active bouts (e.g. number of MVPA bouts lasting ≥ 10 minutes per day).

However, like pedometers, accelerometers are limited by a poor response to cycling, skating, load-carrying, and other non-ambulatory activities and they cannot account for the additional cost of climbing hills or making movements against external resistance [48]. Many different brands of accelerometers are available [73], but over the last 20 years the most commonly used monitors within the PA research field have been those manufactured by ActiGraph (ActiGraph, LLC, Pensacola, Florida, USA). Since we based our studies and this thesis on this specific brand, the following section focuses on ActiGraph accelerometers.

ActiGraph accelerometers

Formerly known as Computer Science and Application (CSA) and Manufacture Technology Incorporated (MTI), ActiGraph first came out with an accelerometer-based activity monitor in 1993. The first generation ActiGraph activity monitor, the 7164, sampled vertical accelerations using a piezoelectric accelerometer and has been used extensively, e.g. in the National Health and Nutrition Examination Survey (NHANES) in the U.S. [68]. However, the monitor was limited by a non-rechargeable battery, small storage capacity, and inability to store raw accelerations for later processing (i.e. it only stored proprietary activity counts). In 2005, the GT1M model replaced the 7164 model. It had a rechargeable battery, better storage capacity, and the ability to store data in a pre-filtered raw mode. The change to a capacitive micro electro-mechanical system (MEMS) based accelerometer however represented the biggest technological difference between the two models. More recently, ActiGraph have also released the GT3X (2009) and GT3X+ (2010) models. Aside from the ability to measure tri-axial accelerations (vertical, medio-lateral, and antero-posterior), even better storage capacity and battery life, and a higher sampling frequency capability, the accelerometer technology used in the GT1M, GT3X, and GT3X+ models is essentially the same [74].

Reliability and validity of ActiGraph accelerometers

The technical reliability of ActiGraph accelerometers has been tested using different setups in the laboratory, indicating relatively good intra- and inter-instrument reliability [75-81]. In addition to technical reliability, PA assessment periods need to be representative of long-term habitual PA. In large-scale studies, a lack of feasibility renders it rare to employ longer-than-seven-day assessment protocols. However, because participants with unusual activity levels during assessment largely average each other out, as little as one randomly selected day of ActiGraph assessment (minimum wear time ≥ 10 hours) may be sufficient to get reliable estimates of group level means in children and adolescents [82]. Others suggest that between two and seven days (minimum wear time ≥ 6 to ≥ 10 hrs/d) is necessary to achieve acceptable reliability (ICC coefficient ≥ 0.8), depending on participant characteristics and the PA outputs under study [83-88].

ActiGraph activity counts show a strong to very strong correlation with energy expenditure measured by indirect calorimetry during structured walking and running protocols (r = 0.71-0.96) [76, 89-92]. However, the correlation is weaker in validation studies where participants perform choreographed routines designed to simulate a variety of lifestyle physical activities (r = 0.55-0.59) [93-95]. Activity counts correlate poorly with energy expenditure during cycling (r = 0.04) [96], and running speeds > 9 km/h [76].

Activity counts from the ActiGraph accelerometer have repeatedly been shown to significantly correlate with DLW-derived energy expenditure and PAL in free-living children and adolescents [73, 97]. The correlations are inevitably weaker than during structured walking and running protocols in the laboratory, but studies in both children [98] and adolescents [99, 100] have reported correlation of at least moderate strength (r ≥ 0.51).

Several different approaches have been used to derive the linear relationship between activity counts and energy expenditure and delineate activity count cut-points used to partition awake time into sedentary time (ST), light PA (LPA), moderate PA (MPA), vigorous PA (VPA) and MVPA [101]. There is still no consensus on what cut-points to use in children and adolescents. However, the widely applied cut-point of < 100 counts per minute (cpm) for ST exhibits good-to-excellent classification accuracy [102]. A cut-point between 2000-2500 cpm seems to perform reasonably well in classifying ambulatory MVPA in children and adolescents [102].

1.4 Physical activity levels in children and adolescents

Since the late 1990s, a large number of studies have assessed PA in children and adolescents using ActiGraph accelerometers (Appendix 1). Throughout this period, a lack of consensus on how to process accelerometer data has made comparisons between studies challenging [29, 103-

106]. However, several research groups have recently joined forces and pooled ActiGraph data from 20 studies worldwide to create the International Children's Accelerometry Database (ICAD) [107]. This facilitates reanalysis using the same methodology across studies, largely overcoming previous comparability problems.

Utilizing ICAD data on almost 30,000 2.8–18.4 year olds from 10 countries, Cooper et al. (2015) found that PA was consistently lower in girls than in boys, lower in overweight/obese youth, and decreased cross-sectionally each year after age five [108]. This confirms what many other studies have reported previously (Table 2). Furthermore, the authors revealed substantial differences in PA between countries for both sexes and noted that all countries were alike in showing the same differences in PA by sex, age, and (almost always) by weight status [108].

Table 2 shows a selection of studies that have assessed overall PA (cpm) and/or min/d spent in MVPA in children and adolescents using ActiGraph accelerometers. As can be seen, overall PA and MVPA are consistently lower in girls compared to boys and PA declines cross-sectionally with increasing age. The latter does however seem more evident within than between studies. Table 2 also exemplifies how daily minutes of MVPA will vary considerably depending on the cut-point used to define MVPA [103]. Roughly speaking, girls spend ~60 min/d and boys spend ~80 min/d in MVPA when MVPA is defined using a cut-point of ≥ 2,000 cpm. When the cut-point is increased to 2,242/2,296 cpm, girls spend ~40 min/d and boys ~55 min/d in MVPA. Lastly, after re-analyzing data from 14 of the studies included in ICAD using a MVPA cut-point of ≥ 3,000 cpm, Ekelund et al. (2012) reported that girls and boys spend 24 and 37 min/d in MVPA, respectively [10].

The proportion of children and adolescents adhering to PA guidelines (and defined as "physically active") will not only depend on the MVPA cut-point used, but also on the interpretation of guideline adherence [103, 108]. If we take the guideline at face value, i.e. ≥ 60 minutes of MVPA *every* day, the proportion adhering to the guideline will inevitably be lower than if an *average* ≥ 60 min/d is used. Multi-national studies in children [108, 109, 115, 117] and adolescents [108, 109, 113] have reported prevalence values based on both guideline adherence interpretations.

Table 2: Selected studies that have used ActiGraph accelerometers to assess overall physical activity (cpm) and minutes per day spent in MVPA

Study	**Country**	**Age**	**n** total (% boys)	**Overall PA (CPM)** total / girls / boys	**MVPA (min/day)** total / girls / boys
					*(≥2000 cpm)**
[109] Nilsson	Denmark	9	301 (47)	--- / 606 / 716	-- / 57 / 83
et al. (2009) [A]	Portugal	9	292 (52)	--- / 601 / 735	-- / 66 / 93
	Estonia	9	299 (51)	--- / 659 / 792	-- / 74 / 101
	Norway	9	292 (52)	--- / 731 / 873	-- / 85 / 111
	Denmark	15	198 (43)	--- / 414 / 432	-- / 41 / 45
	Portugal	15	162 (49)	--- / 464 / 615	-- / 51 / 79
	Estonia	15	272 (37)	--- / 497 / 661	-- / 62 / 86
	Norway	15	138 (42)	--- / 549 / 672	-- / 67 / 86
					*(≥2000 cpm)**
[110] Kolle	Norway	9	1,127 (53)	--- / 693 / 796	87 / 76 / 95
et al. (2010)		15	697 (48)	--- / 487 / 542	65 / 62 / 68
					*(≥2000 cpm)**
[111] van Sluijs et al. (2008)	Great Britain	10	1,868 (44)	671 / 636 / 717	74 / 66 / 84
					*(≥2000 cpm)**
[112] Owen et al. (2009)	Great Britain	10	2,071 (48)	482 / 445 / 525	69 / 61 / 78
					*(≥2000 cpm)**
[113] Ruiz et al. (2011) [B]	Multiple	15	2,200 (46)	410 / 370 / 464	55 / 49 / 64
					*(≥2242 cpm)**
[114] Griffiths et al. (2013)	Great Britain	7	6,497 (49)	595 / 561 / 630	60 / 54 / 67
					*(≥2296 cpm)**
[115] Konstabel	Multiple	6	1,206 (51)	--- / 559 / 631	-- / 37 / 50
et al. (2014) [C]		7	1,703 (48)	--- / 549 / 610	-- / 39 / 52
		8	1,195 (49)	--- / 518 / 581	-- / 36 / 49
		9	574 (47)	--- / 481 / 551	-- / 36 / 48
		10	258 (46)	--- / 471 / 540	-- / 35 / 48
					*(≥2296 cpm)**
[116] Katzmarzyk et al. (2015) [D]	Multiple	10	6,539 (46)	--- / --- / ---	-- / 52 / 70
					*(≥3000 cpm)**
[10] Ekelund et al. (2012) [E]	Multiple	11	20,871 (52)	--- / 540 / 642	30 / 24 / 37

--, not reported; CPM, counts per minute; MVPA, moderate-to-vigorous physical activity (mean or median); *. Cut-point used to define MVPA. **A** The European Youth Heart Study (EYHS) (Denmark, Portugal, Estonia, and Norway). For this presentation, we have recalculated the weekday and weekend day specific values presented by [109] using the following formula: (weekday values x 5)+(weekend values x 2)/7. **B** The Healthy Lifestyle in Europe by Nutrition in Adolescence (HELENA) Study includes samples from Greece, Germany, Belgium, France, Hungary, Italy, Sweden, Austria, and Spain (age range 12.5–17.49 years) **C** The Identification and prevention of dietary and lifestyle-induced health effects in children and infants (IDEFICS) study includes samples from Sweden, Germany, Hungary, Italy, Cyprus, Spain, Belgium and Estonia). **D** The International Study of Childhood Obesity, Lifestyle and the Environment (ISCOLE) includes samples from Australia, Brazil, Canada, China, Colombia, Finland, India, Kenya, Portugal, South Africa, United Kingdom, and the United States (mean±sd age 10.4±0.6 years). **E** Data from the International Children's Accelerometry Database (ICAD) (age range 4-18 years. The presented cpm and MVPA values are based on accelerometer data from 14 studies, including the same data used by Nilsson et al. (2009) and Van Sluijs et al. (2008) [109, 111].

Defining guideline adherence as an *average* of ≥ 60 min/d and using a 2,000 cpm MVPA cut-point, the European Youth Heart Study found that ~60% (Denmark) to ~90% (Norway) of 9-year olds adhered to the guideline on weekdays [109]. On weekend days, the prevalence values were somewhat lower, ranging from ~38% (Denmark) to ~62% (Norway). Among 15-year olds, the prevalence values ranged from ~25% (Denmark) to ~70% (Norway) on weekdays and ~18% (Denmark) to ~38% (Portugal, Estonia, and Norway) on weekend days [109]. Notably, the prevalence values in Denmark were likely underestimated, because cycling is a very common activity in that particular population [96, 118]. In the HELENA study, in which 12.5-17.5 year olds from nine European countries participated, 56.8% of boys and 27.5% of girls adhered to the guideline on a weekly basis when the same guideline adherence definition and MVPA cut-point was used [113]. The prevalence values were similar in Southern European (53.7%) and Central-Northern European (58.6%) boys. However, the prevalence values were significantly different between Southern European (19.9%) and Central-Northern European girls (32.2%) [113].

In contrast, Cooper et al. (2015) found that only 9.0% of boys and 1.9% of girls adhere to the "face-value" interpretation of the guideline when using a MVPA cut-point of ≥ 2,296 cpm in the ICAD [108]. Furthermore, sub-analyses of 9-10 year olds revealed the highest guideline adherence to be a modest ~13% in Norwegian girls and ~30% in Norwegian boys. Among 12-13 year olds, the prevalence values did not exceed 5% in girls and 10% in boys in any of the represented countries. This is in line with the prevalence values reported from two other multi-national datasets using the same MVPA cut-point and guideline interpretation [115, 117]. In the IDEFICS study, the percentages among European children (2.0-10.9 years old) ranged from 2.0% (Cyprus) to 14.7% (Sweden) in girls and from 9.5% (Italy) to 34.1% (Belgium) in boys [115]. In the ISCOLE study, in which 9-11 year-old children from all five continents are represented (12 countries), 4.8% spent ≥ 60 minutes on MVPA *every* day, 2.4% of girls and 7.6% of boys [117]. The highest compliance was observed in Finnish children, the lowest in Chinese and U.S. children (sample specific prevalence not shown) [117].

Lastly, it is important to note that very few studies have sampled their participants to be nationally representative. Only two of the samples included in ICAD [119] and none of the samples included in the other aforementioned multinational studies [109, 113, 115, 117] were designed to be nationally representative. Although some samples include a large number of participants, they are often drawn from small geographic areas (e.g. cities, municipalities) or based on convenience.

1.4.1 Secular trends in physical activity

Urbanization and mechanization during the last century has reduced the necessity to be physically active in everyday life, especially in westernized countries. Because of the increase in the prevalence of overweight and obesity among children and adolescents [120, 121], it is a common perception that young people today are less physically active than in previous generations. However, most of the available data on secular trends in PA are based on self-reports [122-133] and no studies incorporating secular trends in PA in youth are available earlier than 1977 [132]. Taken together, these studies suggest that the PA levels of youth remained relatively stable or increased between the 1980s and the early to mid-2000s in westernized countries. A recent review has however suggested that the proportion of adolescents (age 11-17) not achieving ≥ 60 min/d of MVPA increased between 2012 and 2016 in 32 of the 50 countries investigated [134]. Because self-reports are prone to recall and social-desirability bias [30, 135], the validity of these cross-generational comparisons are limited.

A handful of studies have investigated secular trends in objectively assessed PA in children and adolescents, none with a baseline prior to 1997, and only two with nationally representative datasets (Table 3).

Accelerometer data indicate a slight increase in overall PA and the proportion meeting PA recommendations among Norwegian 9-year olds between 1999/2000 and 2005/06 [136]. Further, accelerometer data also indicate that overall PA and time spent in MVPA among 6-11 year olds in the U.S. was slightly higher in 2005/06 compared to 2003/04 [137] and that there was a slight increase in MVPA between 1997/98 and 2003/04 in 8-10 year-old Danish children [138]. These findings corroborate pedometer data from Swedish 7-9 year olds and 13-14 year olds, revealing stable or increased mean steps/d in 2006 and 2008 compared to 2000, respectively [139, 140]. However, this is contrasted by pedometer data from Czech adolescents, suggesting a secular decrease in the weekly number of steps achieved by boys and girls between 1998/2000 and 2008-10 [141]. In addition, pedometer data from nationally representative samples of Canadian children and adolescents revealed an increase in steps/d between 2005/06 and 2007/08, but a decrease thereafter until 2012-14, with steps/d being significantly lower in 2012-14 compared to 2005/06 in all age groups (ages 5-10, 11-14, and 15-19) [56]. No published studies have investigated secular changes in accelerometer assessed PA in population based samples of children and adolescents from the mid-2000s onward.

Table 3 Studies investigating secular trends in objectively assessed physical activity

Country	Cohorts	Age	n (♂/♀)	Overall PA (cpm/steps) (♂/♀)	MVPA min/d (♂/♀)	PA rec. (%) (♂/♀)	Monitor
DEN (1)	'97-'98	9-10	178/203	767/601	195/154		Acc.
	'03-'04	9-10	178/238	774/622	206/165		Acc.
NOR (2)	'99-'00	9	173/167	782	90	87/75	Acc.
	'05	9	209/169	831	92	93/79	Acc.
USA (3)	'03-'04	6-11	265/288	651/566	97/75		Acc.
	'05-'06	6-11	319/325	677/597	101/78		Acc.
	'03-'04	12-19	577/535	484/357	40/22		Acc.
	'05-'06	12-19	549/523	463/354	37/21		Acc.
SWE (4)	'00	7-9	183/153	15,991/13,788		60/75 [b]	Ped.
	'06	7-9	86/83	16,973/15,141		67/90 [b]	Ped.
SWE (5)	'00	13-14	124/111	15,623/12,989		65/62	Ped.
	'08	13-14	79/107	15,174/13,338		69/68	Ped.
CZE (6)	'98-'00	16	136/114			68/75 [d]	Ped.
	'08-'10	16	136/230			55/74 [d]	Ped.
CAN (7)	'05-'06	5-19	5,500 [a]	11,643/10,249		11/8 [e]	Ped.
	'06-'07	5-19	5,500 [a]	12,059/10,756		14/12 [e]	Ped.
	'07-'08	5-19	5,500 [a]	12,202/11,040		14/13 [e]	Ped.
	'08-'09	5-19	5,500 [a]	11,357/10,253		12/9 [e]	Ped.
	'09-'10	5-19	5,500 [a]	11,759/10,331		10/8 [e]	Ped.
	'10-'11	5-19	5,500 [a]	11,208/10,097		8/9 [e]	Ped.
	'11-'12	5-19	5,500 [a]	11,313/10,150		9/8 [e]	Ped.
	'12-'14	5-19	5,500 [a]	10,932/9,830		8/8 [e]	Ped.

1: [138] (Municipality of Odense, Denmark, MVPA ≥ 1,000 cpm). **2**: [136] (Oslo, Norway, MVPA ≥ 2,000 cpm). **3**: [137] (Nationally representative USA, MVPA 4 METs). **4**: [139] (Five schools in South-Eastern Sweden). **5**: [140] (One school in Sweden). **6**: [141] (Random sample of Czech high schools). **7**: [56] (Nationally representative samples from Canada). [a] Varied from 6,627 in '06-'07 to 3,883 in '11-'12. Participation was roughly equal amongst boys and girls. [b] 12,000 and 15,000 steps per day for girls and boys, respectively. [c] 12,000 and 13,500 steps per day for girls and boys, respectively. [d] ≥ 9,000 steps per day for girls, ≥ 11,000 steps per day for boys [e] ≥ 10,000 steps/day for 5-year olds, ≥ 13,000 steps/day for 6–11 year-old boys, ≥ 11,000 steps/day for 6–11 year-old girls, and ≥ 10,000 steps/day for 12–19 year olds.

Ref., reference; PA, physical activity; cpm, counts per minute; MVPA, moderate-to-vigorous physical activity; PA rec., physical activity recommendation adherence; Acc., accelerometer; Ped., pedometer; ♂/♀, boys/girls.

1.4.2 Longitudinal trends in physical activity

To study longitudinal PA trends in children, it is important to identify critical time points of behavior change and to identify whether age-related changes vary between different sub-populations (e.g. girls vs. boys, high socioeconomic status (SES) vs. low SES). Although results from cross-sectional studies render little doubt that PA levels decline through childhood and adolescence, cross-sectional data might be subject to cohort effects [142], i.e. observed differences between children and adolescents at one time point may not be equivalent to within-individual changes from childhood to adolescence. Thus, longitudinal data is needed to describe age-related changes in PA patterns more accurately.

Dumith et al. conducted the first systematic review of studies investigating longitudinal trends in PA during adolescence and from childhood to adolescence in 2011 [143]. The review identified

26 studies, only two of which included objective assessments of the intensity of PA (accelerometry), and most of which had completed their data collection before the year 2000. The review revealed consistent evidence showing that PA declines by an average of 7% per year during adolescence and suggestive evidence that declines have been greater in girls than in boys in more recent studies (8.2% per year for the period 1998–2007).

Table 4: Selected studies investigating longitudinal changes/trends in ActiGraph-assessed PA from childhood to adolescence (ordered by publication year)

Country (ref)	Age	n (♀/♂)	Monitor	Epoch	CPM (♀/♂)	ST (min/d) (♀/♂)	LPA (min/d) (♀/♂)	MVPA (min/d) (♀/♂)
DEN [150]	9	96/112	7164	60	708/599			
	15	96/112	7164		492/398			
ENG[A] [144]	12	742/599	7164	60	544/632	442/430	317/333	18/26
	14	742/599	7164		478/584	504/476	266/289	19/28
	16	742/599	GT1M		430/536	529/513	235/253	19/30
USA[B] [146]	9	407/391	7164	60		312/309	385/372	44/60
	11	382/369	7164			350/342	330/325	32/47
	12	290/286	7164			369/353	299/287	27/38
	15	217/253	GT1M			467/464	197/206	15/28
SWE[C] [151]	9	213/180	7164	60		305/308		73/100
	15	133/107	GT1M			482/486		44/52
EST[D] [151]	9	220/214	7164	60		360/326		61/80
	18	149/114	GT1M			496/506		52/59
USA[E] [145, 147]	5	203/184	7164	60	514/562			48/60
	9	248/245	7164		453/546			46/65
	11	247/250	7164		410/515			40/64
	13	238/243	7164		331/430			33/52
	15	204/212	GT1M		243/315			26/38
	17	195/192	GT3X		-/-			24/36
ENG[F] [152]	10	173/146	GT1M	5	639/725			68/84
	14	173/146	GT1M		463/531			60/67
ENG[G] [149]	7	214/217	GT1M	15	746/780			63/76
	9	219/209	GT1M		653/715			56/70
	12	209/176	GT1M		469/558			47/60
	15	147/131	GT1M		400/482			41/51

A Cut-points (ST, LPA, MVPA), < 100 cpm, 100-3,599 cpm, ≥ 3,600 cpm. **B** Cut-points (ST, LPA, MVPA), < 100 cpm, 100-2,295 cpm, ≥ 2,296 cpm. **C** Cut-points (ST, LPA, MVPA), < 100 cpm, 100-1,999 cpm, ≥ 2,000 cpm. **D** Cut-points (ST, LPA, MVPA), <100 cpm, 100-1,999 cpm, ≥ 2,000 cpm. **E** Cut-point (MVPA), ≥ 2,296 cpm. **F** Cut-point (MVPA), ≥ 2,000 cpm. **G** Cut-point (MVPA), ≥ 2,296 cpm. CPM, counts per minute; ST, sedentary time; LPA, light physical activity; MVPA, moderate-to-vigorous physical activity; min/d, minutes per day; ♀/♂, girls/boys.

Studies that have investigated longitudinal PA changes from childhood to adolescence using objective data remain limited. Table 4 shows studies identified through a recent literature search where PA has been assessed using ActiGraph accelerometers at two or more time points. Although they vary in terms of baseline age, age at last follow-up assessment, and time between baseline and last follow-up assessment, all reported a decline in overall PA or MVPA from baseline to follow-up. Furthermore, the relative declines in overall PA and MVPA seem similar among boys and girls. One study did report stable levels of MVPA from 12 to 16 years [144], suggesting that the age-related decline in overall PA can be accounted for by a reallocation of time spent in LPA to ST. However, this may also be due to the much higher cut-point used to define MVPA (3,600 cpm) than in the studies observing declines between similar ages [145-147]. Thus, it might support the notion that VPA can increase during adolescence, even in the presence of an overall decline in PA, which has been suggested previously [148].

Together, these recent studies provide an emerging body of evidence challenging the belief that PA levels are adequate during childhood and decline dramatically during adolescence and that adolescent declines are greater in girls than in boys [149]. This provides valuable new information, suggesting that future interventions aimed at preventing physical inactivity should begin well before adolescence and focus equally on boys and girls. However, there is still a scarcity of longitudinal and objective PA data, and the generalizability of previous studies is limited.

1.5 Physical activity and adiposity in children and adolescents

1.5.1 Adiposity in children and adolescents

Underwater weighing and dual-energy X-ray absorptiometry (DXA) have high reliability and validity and are regarded as the gold standards of body composition assessment [153]. However, their use in large-scale epidemiological research is limited due to their complexity and cost. Several proxy measures based on anthropometrics have therefore been developed and used to assess body composition in public health evaluations [154]. Of these, body mass index (BMI) and waist circumference (WC) are the most commonly used methods. Although their accuracy is limited at the individual level, they provide valuable proxy measures of total adiposity (BMI) and abdominal adiposity (WC) in children and adolescents at the population level [153, 155].

A number of studies have found unfavorable associations between adiposity and cardio-metabolic risk in children and adolescents. In a recent systematic review, it was concluded that whatever the definition used for abdominal adiposity and whatever the methods used for anthropometric measurements, central body fat deposition in children and adolescents increases cardio-metabolic risk [156]. Importantly, research is also showing that obesity is associated with poorer psychosocial functioning in children and adolescents, even compared with other chronic diseases [157]. In light of the large increase in the prevalence of overweight and obesity among children and adolescents over the last 30-40 years, this is of major concern [121, 158]. Worldwide, the age-standardized prevalence of obesity in children and adolescents increased between 1975 and 2016 from 0.7% to 5.6% in girls (from 5 to 50 million), and from 0.9% to 7.8% in boys (from 6 to 74 million) [158]. Furthermore, there was a large increase in the age-standardized prevalence of overweight and obesity combined (equivalent to adult BMI $\geq$ 25) in both developed (from ~16.5% to ~23.2%) and developing (from ~8.3% to ~13.2%) countries between 1980 and 2013 [121].

1.5.2 The role of physical activity in the prevention of adiposity

Physical activity is advocated to play a key role in the prevention of excessive weight gain during childhood and adolescence [4]. However, because most studies investigating the link between PA and adiposity in children and adolescents are cross-sectional by design, assess PA via self-reports, and fail to accurately account for diet, the effect of PA in adiposity prevention is debated [159, 160].

It is plausible that associations between PA and adiposity are bidirectional, i.e. low levels of PA may both be a cause and consequence of adiposity [161]. Both cross-sectional [9, 10, 162-165] and prospective cohort studies [70, 166, 167] have found time spent in objectively assessed MVPA to be inversely associated with different markers of adiposity in children. However, studies also show that adiposity is inversely associated with objectively assessed MVPA [168, 169]. This has later been confirmed in Mendelian randomization analysis, strongly supporting a causal relationship [170]. This, together with the limited success of PA interventions in reducing adiposity [171-174], has led some to conclude that the relationship between adiposity and PA is dominated by the impact of adiposity on PA and not at all by PA on adiposity [169, 175]. However, it is important to consider the different levels of accuracy of PA and adiposity assessments when discussing the relative importance and direction of causality between the two factors [159]. Because epidemiological/field-based PA assessments have a considerably larger level of inaccuracy than both direct (e.g. DXA) and indirect (e.g. BMI and WC) assessments of adiposity, regression dilution bias may severely underestimate associations when PA is modeled as the exposure rather than the outcome [176]. Furthermore, it is important to interpret the results from interventional studies in light of the limited success they have had in actually increasing children's PA levels [177].

Because of the long follow-up and potential ethical issues it would entail, it is highly unlikely that the relative importance and direction of causality between adiposity and PA can be properly addressed in randomized controlled trials [9, 178]. Hence, we probably need prospective cohort studies assessing free-living PA with a higher degree of accuracy than is currently possible in order to reach more definitive conclusions. However, recent years have seen the emergence of new statistical approaches that may also increase the understanding of the relationship between PA and adiposity. Isotemporal substitution modeling is one such approach. It tries to address one of the caveats of statistical models previously used to study the relationship between physical activities and adiposity. Specifically, it addresses the fact that the potential benefits of different physical activities depend not only on the specific activity (e.g. walking), but also on the activity it displaces (e.g. sleeping, watching TV, or running) [179]. Isotemporal substitution modeling is particularly suited for data collected with accelerometers because it assesses PA continuously over a finite period of wear and covers the entire intensity spectrum from ST to VPA [180].

A handful of studies have used isotemporal substitution modeling to study the association between PA and adiposity. Results indicate that substitution of ST with MVPA is favorably associated with adiposity in children [181-185], but not in adolescents [184]. Whether substitution of ST with LPA is associated with adiposity remains unclear. Only one previous study has used isotemporal substitution modeling to study the prospective association between PA and adiposity [185]. The authors of this study observed that substituting ST with MVPA at age 10 was favorably associated with adiposity at age 11.5. However, it remains to be determined whether this association persists over longer periods.

1.6 Correlates and determinants of physical activity

A multitude of factors may affect the PA level of children and adolescents and investigations into these factors are essential for the development of sound public health interventions aimed at increasing PA. Indeed, in recent decades a large number of investigations into correlates (factors associated with PA) and determinants (factors with a causal relationship with PA) of PA have been carried out [186]. These can be classified as *individual* (e.g., biological, psychological, and behavioral aspects), *interpersonal* (e.g., relationships with parents, relatives, peers, and socio-cultural networks), *environmental* (e.g., access to/availability of tools/services, and proximal/distal built/natural surroundings), and *policy related* (e.g., organizational and governmental aspects) [187]. However, the evidence regarding correlates and determinants of PA is still inconclusive [188]. Hence, there is a continued need for studies investigating potential correlates and determinants of

PA in children and adolescents. The following describes current evidence regarding six potentially modifiable factors suggested to influence the PA level of children and adolescents.

1.6.1 Schools' outdoor areas

The size of schools' outdoor play areas has received attention as a potential environmental correlate of PA [189]. Studies have both found [190-193] and not found [194, 195] associations between the size of schools' outdoor play areas and objectively assessed PA. When comparing studies, it seems that the schools included in studies finding an association have smaller outdoor play areas per pupil than schools included in studies not finding an association. This is supported by intervention studies finding positive effects of altering the available outdoor play area per pupil during recess in schools with very small outdoor play areas [190, 193, 196]. These intervention studies are however limited by small sample sizes and short follow-up, which limit their generalizability. To increase the understanding of the relationship between the size of schools' outdoor play areas and PA, there is a need for studies with large, representative samples of schools with considerable variation in outdoor play space. Furthermore, no study has investigated whether the size of lower secondary schools' outdoor areas is associated with adolescents' accelerometer-assessed PA level during school hours.

Permanent play facilities, such as swings, sandboxes, climbing frames, basketball hoops, and soccer goals, are basic components of any school's outdoor play area design. Whereas studies conducted among Australian children found no association between permanent play facility availability and objectively assessed PA [190, 197], studies conducted among New Zealand [195, 198], Danish [194], and English children [191] suggest a positive association. However, the strength of the reported associations varies considerably and the studies differ in their conclusions with regard to the actual importance of permanent play facility provision for children's PA during school hours. Moreover, the studies conducted thus far have included relatively small samples of both children and schools and very little is known about the impact of permanent play facility provision on adolescents' objectively assessed PA.

1.6.2 Sleep

Like physical inactivity, sleep insufficiency (short sleep duration and/or poor sleep quality) is associated with negative physical and mental health outcomes in children and adolescents [199]. Therefore, it is recommended that children (6-13 years) and adolescents (14–17 years) sleep 9–11 h/night and 8–10 h/night, respectively [200]. Schmid et al. (2009) were some of the first to test the hypothesis that fatigue and tiredness generally associated with inadequate sleep will cause lower levels of objectively assessed PA [201]. In this small, experimental study, they observed that short-term sleep loss among 15 young men resulted in a decrease in objectively assessed PA.

Since then, several studies have investigated the association between both objectively assessed and self-reported sleep and objectively assessed PA in children and adolescents [202-211]. However, associations remain unclear, with limited evidence from cross-sectional studies of a significant relationship between sleep and PA in children or adolescents.

Studies adopting a day-to-day longitudinal design have reported that neither sleep duration nor sleep efficiency affected mean PA level the following day [204, 205]. Furthermore, in one of these studies, an extra hour spent in bed during the night was followed by a 16-minute decrease in MVPA [205]. To date, only one randomized controlled trial investigating the effect of altered sleep on objectively assessed PA in children exists [208]. Although one week of decreased sleep led to an increase in self-reported TV watching and a decrease in overall PA, the study found no difference in MVPA between decreased, normal, and increased sleep duration among these 37 8-11 year olds [208]. Whether sleep is prospectively associated with PA assessed at later time points than the following day or week remains unknown.

1.6.3 Screen time

Screen time refers to time spent on screen-based behaviors and can be sub-categorized into recreational screen time, stationary screen time, sedentary screen time, and active screen time [18]. Researchers have often used different assessments of screen time as a proxy-measure for ST and sedentary behavior [212] and there is moderate to strong evidence that screen time is associated with obesity, blood pressure, total cholesterol, and physical fitness in children and adolescents [212]. However, this relationship is complex and probably not merely a consequence of sedentariness [16, 213-215]. Because of the ample evidence of the beneficial health effects of MVPA [216], the question of whether screen time displaces participation in MVPA is highly relevant.

Studies do indicate an inverse, cross-sectional association between screen time and PA in children and adolescents [217-220] and suggest that screen time at age six can predict parent-reported PA at ages eight and 10 [221]. However, these studies all assessed PA via self- or proxy-reports. Very few studies have investigated whether screen time is associated with objectively assessed PA. In one study, Bergh et al. (2011) did not find an association between TV watching and objectively assessed MVPA among 1,129 Norwegian 11-year olds, but higher computer/game use in weekends was associated with less MVPA in overweight/obese participants [222]. This lack of a clear association between screen time and objectively assessed MVPA is supported by two other cross-sectional studies in children [223, 224]. Lastly, Hearst et al. (2012) investigated whether screen time was prospectively associated with accelerometer assessed PA in a sample of U.S. 10-16 year olds [225]. Their results did not indicate that screen time at baseline predicted MVPA two years later. Thus, the evidence of an association between screen time and MVPA seems less clear when MVPA is assessed objectively. However, more studies are warranted, especially among adolescents.

1.6.4 Active school transport

Research investigating the contribution of active school transport to children's and adolescents' PA show encouraging results. In a systematic review, Larouche et al. (2014) identified 49 studies examining the association between active school transport and daily PA, 28 of which assessed PA using accelerometry [226]. Active school transport was positively associated with PA in 22 of these, despite the limited ability of accelerometers in measuring PA during cycling. Furthermore, data from the ISCOLE study (n = 6,224) revealed that children who engaged in active school transport accumulated six more minutes per school day of MVPA and had a 80% higher chance of obtaining the recommended ≥ 60 minutes per school day of MVPA, compared to children who used motorized transport to school [227].

A handful of smaller scale randomized controlled trials and quasi-experimental studies have also shown encouraging effects of implementing so-called "walking school buses" on active transport and PA [228-231]. Nevertheless, the majority of evidence to date stems from cross-sectional studies, with limited ability to determine the direction of association between active school transport and PA.

Active school transport can be thought of as part of a young person's PA skillset. Therefore, it can be hypothesized that active transport during childhood may convey self-efficacy regarding PA capacity, potentially lowering the barriers perceived towards PA later in life. However, more studies with longitudinal designs are needed to determine whether active school transport predicts PA at later time points, i.e. from childhood to adolescence and adolescence to adulthood.

1.6.5 Sports participation

The International Society for Physical Activity and Health has deemed sport participation as one of seven "investments that work" in the campaign against physical inactivity [232]. Although this claim has considerable support in the literature on children and adolescents, which consistently shows that sport participants are more likely to be physically active than nonparticipants, most of the evidence was until recently cross-sectional and/or based on self-reported assessments of PA [233]. Because youth can spend less than 50% of practices in different sports in MVPA [234, 235], self-reports are likely to inflate the observed relationships between sports participation and PA, particularly if reported concurrently [236].

Recent studies investigating the relationship between sports participation and accelerometer assessed PA report equivocal findings. Cross-sectional data on 9-16 year-old English boys indicate that soccer is an important source of weekend MVPA, especially in 13-16 year olds [237]. Similar observations are reported by Hebert et al. (2015) in Danish 8-year olds [238], for which participation in soccer and handball was positively associated with daily MVPA. However, they also observed that associations between other sports (gymnastics, basketball, volleyball) and daily MVPA were inconsistent [238]. Basterfield et al. (2014) found a significant positive association between sports club participation and daily MVPA in English 12-year olds, whereas no association was observed in 9-year olds [236]. Finally, Nielsen et al. (2013) observed that Danish children from immigrant backgrounds were no less physically active than other children, despite their much lower participation rate in organized sports [239]. Thus, a more nuanced association between organized sport participation and PA seems evident when PA is assessed with accelerometers.

Importantly, cross-sectional studies cannot rule out reverse causation, i.e. the possibility that more active and fit children choose to join a sports club in the first place. Thus far, only a few prospective studies have investigated whether sports participation is a determinant of objectively assessed PA. Basterfield et al. (2014) did not find sports club participation at age nine to predict accelerometer assessed PA at age 12 [236]. Similar results were also found by Brooke et al. (2014), who reported that neither change in MVPA nor total PA (cpm) from 10 to 14 years of age were predicted by variety or frequency of sports participation at age 10 [240]. Hence, there is currently no evidence indicating that sports participation is a determinant of daily levels of MVPA in children or adolescents.

2. Need for new information

To accurately assess the PA level of children and adolescents and how it changes over time, there is a continuing need for population-based studies quantifying PA using objective, reliable, and valid methods. Although over the last 20 years a large number of studies have used accelerometers to assess PA in children and adolescents, very few have been designed to yield nationally representative data. The four papers this thesis builds upon increase knowledge about PA in children and adolescents. In order to inform public health policy, information about time-dependent and age-related changes in PA is essential. Furthermore, it is important to increase knowledge about the relationship between PA and potential implications to health. In addition, insight regarding correlates and determinants of PA is integral for the development of future PA-promoting interventions.

2.1 Aims of the thesis

- **Paper I**
    1. To investigate whether the PA level and ST of 9- and 15-year olds in 2011/12 differed from that of 9- and 15-year olds in 2005/06 (secular changes).
    2. To investigate longitudinal changes in PA and ST from age nine to 15.

- **Paper II**
    1. To investigate the cross-sectional associations between PA and markers of adiposity in 9- and 15-year olds using isotemporal substitution modeling.
    2. To investigate the prospective associations between PA at age nine and markers of adiposity at age 15 using isotemporal substitution modeling.

- **Paper III**
    1. To investigate the association between the number of permanent play facilities in the school's outdoor play area and PA during school hours in nationally representative samples of Norwegian 6-, 9- and 15-year olds.

2. To investigate the association between the size of schools' outdoor play areas and PA during school hours in nationally representative samples of Norwegian 6-, 9- and 15-year olds.

- **Paper IV**
    1. To investigate whether sleep duration, screen time, active school transport, and sport/exercise participation is associated cross-sectionally with MVPA in nationally representative samples of Norwegian 9- and 15-year olds.
    2. To investigate whether sleep duration, screen time, active school transport, and sport/exercise participation at age nine is associated prospectively with MVPA at age 15.

3. Methods

3.1 Study design and sampling

The four papers that form the basis for this thesis are all based on PANCS. The Physical Activity among Norwegian Children Study was conducted by the Norwegian School of Sport Sciences on behalf of the Norwegian Directorate of Health (NSSS) and serves as the national PA and fitness surveillance system for children and adolescents in Norway. In **papers I, II, and IV**, we have used data collected in both the first (PANCS1) and second (PANCS2) wave of the study, which were conducted in 2005/06 and 2011/12, respectively. **Paper III** is based on data collected in PANCS2.

The first PANCS study is a cross-sectional study of 9- and 15-year olds from randomly selected and nationally representative samples of primary and lower secondary schools. The second PANCS study is both a cross-sectional study and a prospective cohort study. This study includes 6- and 9-year olds from randomly selected and nationally representative primary schools and 15-year olds that had previously participated in PANCS1 at age nine. In addition, PANCS2 also includes a cross-sectional sample of 15-year olds invited from a random sample of seven lower secondary schools that had previously participated in PANCS1. Combined, these two samples of 15-year olds serve as a representative, cross-sectional sample of 15-year olds living in Norway in 2011/12.

Statistics Norway selected the cross-sectional study samples for both waves of PANCS. To attain nationally representative samples, they used a cluster sampling technique with schools as the primary unit. Special needs schools and schools with less than 10 students in either first, fourth, or 10th grade were excluded, as their inclusion would not have been logistically and economically feasible. However, these schools make up less than 5% of the total student mass in Norway. After taking into account geography and population density, Statistics Norway sampled and invited a random selection of the remaining primary and lower secondary schools. From these, we invited all first (PANCS2 only), fourth, and 10th graders.

Figure 1 shows a flowchart of the number of 6-, 9-, and 15-year olds that were invited and participated in PANCS. We invited a total of 2,818 pupils in PANCS1 and 5,603 pupils in PANCS2, of which 2,299 (81.6%) and 3,598 (64.2%) agreed to participate, respectively. In PANCS2, we were able to track and invite back 1,119 of the 1,306 that had participated in PANCS1 at 9 years. Of these, 731 (65.3%) agreed to participate.

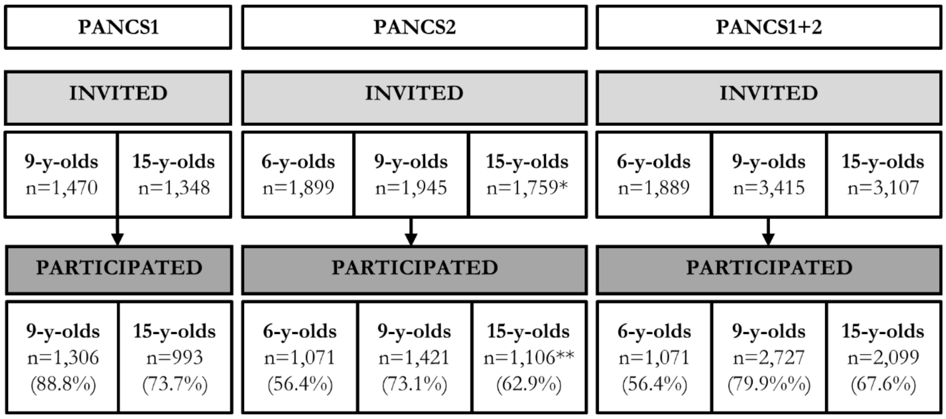

*Figure 1: Flowchart of the study samples in PANCS1 and 2. * Includes 1,119 of the 1,306 9-year olds that participated in PANCS1 and were found and invited to participate in PANCS2 as 15-year olds. ** Includes 731 15-year olds with both cross-sectional and longitudinal data (participated in both PANCS1 and 2) and 375 15-year olds with cross-sectional data only.*

3.2 Ethics

The procedures and methods used in PANCS conform to the ethical guidelines defined in the Declaration of Helsinki and its subsequent revisions. The Regional Committee for Medical Research Ethics and the Norwegian Social Science Data Services approved PANCS1 (Appendix 2). The Regional Committee for Medical Research Ethics deemed PANCS2 to fall outside the Norwegian Health Research Act (Appendix 2). Conventionally, it was therefore approved by the Norwegian Social Science Data Services only (Appendix 2). We sent out information pamphlets outlining the aims, possible hazards, discomforts, and inconveniences of study participation to everyone invited and obtained written informed consent from all participants and their primary guardians before the start of any data collection (Appendix 3). The participants could withdraw partially or fully from the study at any time.

3.3 Sample size

In both PANCS1 and 2, the primary outcome variable was overall PA level (cpm, average number of accelerometer counts registered per minute of accelerometer wear time (counts·min^{-1})). The sample size calculations were based on the ability to detect between-group differences of 7% (two-tailed test) with an assumed Type I error rate of 0.05. However, the sample size calculations performed before the two waves of PANCS differed in terms power and the variability around mean overall PA levels known from prior studies. In PANCS1, sample size calculations were based on a power to avoid a Type II error of 0.8 and the standard deviation (SD) known from the Norwegian part of the European Youth Heart Study (SD = 286) [241]. In PANCS2, sample size calculations were based a power of 0.9 and the SD known from PANCS1 (SD = 280) [110]. After incorporating a design effect of 1.1 due to the cluster sampling, this yielded final target sample sizes per age and sex groups of 488 (444*1.1) in PANCS1 and 567 (516*1.1) in PANCS2.

For our prospective study sample in PANCS2, we invited everyone that we were able to track who participated in PANCS1 at age nine.

3.4 Measures

In PANCS1, we collected data from March 2005 to November 2006. In PANCS2, we collected data from February 2011 to April 2012. No data were collected in July in either study (due to school holidays) and no data were collected in January in PANCS2.

3.4.1 Anthropometry

Trained research assistants performed all anthropometric measurements during school visits (**Papers I-IV**). In PANCS1, the participants wore underwear during the measurements. In PANCS2, the participants wore gym shorts and a t-shirt. To account for this difference, we subtracted 0.3 kg from the PANCS2 participants' weight.

We measured weight and height to the nearest 0.1 kg (Seca 770 (PANCS1) and 877 (PANCS2), SECA GmbH, Hamburg, Germany) and 0.1 cm (wall-mounted measuring tape), respectively. We calculated BMI using the standard formula (weight (kg)/height squared (m^2)). In **Paper II**, we used BMI criteria from the International Obesity Task Force (IOTF) and the WHO to describe the proportion of participants classified as overweight or obese [242, 243]. We calibrated the digital scales used for body weight measurements regularly throughout the study.

We measured WC at the minimum circumference between the lowest rib and the iliac crest using an anthropometric tape measure after normal expiration (**Paper II**). We performed the measurement twice and recorded the average. The intra- (within tester) and inter-class (between tester) correlation coefficients for WC measurements were 0.93 and 0.94, respectively (tested in PANCS1 only).

3.4.2 Physical activity

In both waves of PANCS, we used ActiGraph (ActiGraph, LLC, Pensacola, Florida, USA) accelerometers to assess the participants' level of PA. In PANCS1, we used the 7164 model (often referred to as the CSA 7164 or MTI 7164) (Figure 2). In PANCS2, we used the newer GT1M (version two) and GT3X+ models (Figure 2). The 7164 uses a piezoelectric bimorph beam sensor that detects dynamic accelerations (resulting from motion), whereas the newer models use a MEMS capacitive accelerometer, capable of detecting both static (e.g., force of gravity detected when stationary) and dynamic accelerations [74, 244]. Because the analog components in 7164 model can fluctuate, we calibrated the devices against a standardized vertical movement on a regular basis in PANCS1. This was unnecessary in PANCS2, because upon installing the accelerometers in the newer devices' circuits, their response to the 1g acceleration of the earth is fixed and does not drift [244].

Figure 2: The ActiGraph accelerometers used to assess PA in PANCS1 (model 7164 (left, 4.5 x 3.5 x 1 cm, 43g) and PANCS2 (model GT1M (middle), 3.8 x 3.7 x 1.8 cm, 27g / GT3X+ (right), 4.6 x 3.3 x 1.5 cm, 19g).

Assessment protocol

In both studies, the monitors were fitted to the participants' right hip using an elastic band (Figure 3). We instructed the participants to wear the device at all times except when sleeping or doing water-based activities. The storage capacity of the ActiGraph 7164 used in PANCS1 is limited to four days when accelerations are stored using 10-second epochs. Therefore, we initialized the monitors to record activity on two weekdays and two weekend days (Thu-Sun, Fri-Mon, or Sat-Tue). In PANCS2, we initialized the monitors to record activity for seven days following the initial test day. In order to reduce the possible impact of reactivity, we initialized the monitors to start recording at 06:00 the day after the participants received them, allowing for a one day familiarization period. This is recommended to reduce reactivity bias when PA is assessed in children using accelerometers [245].

Figure 3: ActiGraph accelerometer worn at the right hip.

In PANCS1, we used an ActiGraph Reader Interface Unit with RIU software (K64, Computer Science & Application Inc., Shalimar, Florida, USA) to initialize the monitors and to download the accelerometer files. In PANCS2, this was done using the ActiLife software (ActiGraph, LLC, Pensacola, Florida, USA).

Data reduction

For this thesis, all the accelerometer files from PANCS1 and 2 were re-analyzed and harmonized using KineSoft (v3.3.76; KineSoft, Rothesay, New Brunswick, Canada). For **Papers I-IV**, we analyzed the participants' PA using vertical accelerations collapsed into units called counts (one count is equal to 16 milli gs per second), which were stored every 10 seconds (epoch). These activity counts simply represent the summation of the accelerations measured during the epoch period. In PANCS1 and 2, the raw acceleration signal was sampled at a rate of 10 and 30 Hz, respectively, before it was converted to counts per epoch.

For **Papers I-IV,** the following types of outcome variables were derived from the accelerometers: 1) overall PA level (cpm (counts·min^{-1})); 2) minutes of intensity specific PA per day (the sums of epochs with cpm values below or above specified thresholds); and 3) prevalence of adherence to PA recommendations.

We calculated cpm by dividing the sum of activity counts recorded on valid days by the sum of wear minutes on valid days (valid school days in **Paper III**). Time (minutes) spent in the intensity specific PA categories were derived by summing all epochs containing cpm values falling within the cut-points presented in Table 5. The cut-points we used to define ST are widely applied and have been shown to provide a realistic estimate of the time children spend doing sedentary activities and to exhibit excellent classification accuracy when validated against direct observation and indirect calorimetry [102, 246]. The lower MPA and MVPA cut-point was developed for the European Youth Heart Study and is equivalent to a walking speed in children and adolescents of ≥ 4 km/h, which is probably at the low end of moderate intensity [9]. The VPA cut-point was chosen as it relates roughly to the breaking point between walking and running in children [102, 247]. Time registered above the ST cut-point but below the MPA/MVPA cut-point was categorized as LPA. We categorized the participants as compliant with the Norwegian PA recommendations if they accumulated an average of ≥ 60 min/d of MVPA during the valid days of assessment.

*Tabell 5. Cut-points used to define intensity specific physical activity (**Papers I-IV**)*

	Cut-points	
	Counts per epoch (10 sec)*	**Counts per minute (CPM)**
Sedentary time (ST)	< 17	< 100
Light PA (LPA)	17-333	100-1,999
Moderate PA (MPA)	333-999	2,000-5,999
Vigorous PA (VPA)	≥ 1,000	≥ 6,000
Moderate-to-vigorous PA (MVPA)	≥ 333	≥ 2,000

*Values are rounded. PA, physical activity.

Wear time validation

In **Papers I-IV**, we defined all intervals of ≥ 20 consecutive minutes with no activity recorded as non-wear. In **Papers I, II and IV**, we also excluded data recorded between midnight and 6 a.m. In **Paper III**, we only wanted to assess PA during school hours. Therefore, we excluded data not recorded between 9 a.m. and 1 p.m. (6- and 9-year olds) and between 9 a.m. and 2 p.m. (15-year olds) on weekdays.

After exclusion of non-wear intervals and activity recorded between 00:00 and 06:00, we deemed all days with ≥ 480 minutes of activity recordings valid in **Papers I and II** and included participants with ≥ 2 valid days in the analysis. In **Paper III**, we deemed schooldays with < 60 minutes of non-wear valid and included all participants with ≥ 2 valid schooldays in the analysis. In **Paper IV**, we deemed all files with ≥ 2 weekdays consisting of ≥ 480 minutes of activity count recordings valid and eligible for analysis. Table 6 shows the mean (±SD) minutes of accelerometer wear time per day of participants with sufficient PA data to be included in **Papers I and II**, **Paper III**, and **Paper IV**.

Table 6: Mean (±SD) minutes of accelerometer wear time (WT) per day in participants included in Studies I-IV

	Papers I-II		Paper III		Paper IV	
	n	**WT (min/d) [a]**	**n**	**WT (min/d) [b]**	**n**	**WT (min/d) [a]**
PANCS1						
9-year olds	1,127	774±65	-	-	1,028	816±69
15-year olds	702	795±90	-	-	597	865±92
PANCS2						
6-year olds	1,006	731±55 [c]	968	238±4		-
9-year olds	1,345	771±63	1,288	237±5	1,338	796±60
15-year olds	972	789±83	784	294±9	957	825±84
PANCS1+2						
Age 9	558	794±74	-	-	517	817±67
Age 15	558	780±62	-	-	517	824±85

[a] Of a maximum of 1,080 min/d (06:00-00:00). [b] Of a maximum of 240 min/d (9 a.m.-1 p.m. (6- and 9-year olds)) and 300 min/d (9 a.m.-2 p.m. (15-year olds)). [c] 6-year olds were not included in **Paper I.** WT, wear time. min/d, minutes per day.

3.4.3 Socioeconomic status

We categorized the participants into three (**Papers I, II, and IV**) and four (**Paper III**) SES groups based on their parent/guardian with the highest level of education. The parents self-reported attained education level in PANCS1, whereas in PANCS2, we used registry data provided by Statistics Norway. In **Papers I, II, and IV**, the three SES categories were "low" (primary school or lower secondary school), "middle" (high school [vocational or general studies]), and "high" (University College or University). In **Paper III**, the four SES categories were "low" (primary school, lower secondary school, vocational high school), "middle low" (secondary school/high school), "middle high" (undergraduate degree), and "high" (graduate degree).

3.4.4 Schools' outdoor area

In **Paper III**, the number of permanent play facilities (PPF) in the participating schools' outdoor play area was registered using a standardized form (Appendix 4). To obtain comparable data between schools, we divided the absolute number of PPF in the school's outdoor play area by the total number of students attending the school (PPF per student). Further, we measured the size of the schools' outdoor play areas (m^2 per student) using a polygon measurement tool and updated electronic maps from the Norwegian Mapping Authority [248]. We calculated the m^2 of outdoor play space by subtracting buildings, car parks, and other areas deemed unsuitable for outdoor play from the school's total outdoor area. Using the same polygon measurement tool, we also calculated how many m^2 of the asphalt-covered outdoor play area had a soft surface and was covered by tree shadow. Lastly, we interviewed staff members at each school about recess organization and rules potentially affecting the relationship between PPF availability, play area size, and PA (Appendix 4).

3.4.5 Sleep

In **paper IV**, we estimated sleep duration on schooldays from the participants' self-reported times of going to bed at night and getting out of bed in the morning (Appendix 5). We subtracted and added 0.5 hours from/to the lower ("before 06:30/20:00") and upper categories (08:00/24:00), respectively, and used the halfway point within the remainder of categories (e.g. "Between 06:30 and 07:00" was recoded to 06:45). We then applied the following algorithm to approximate the participants' sleep duration on a numeric, continuous scale:

((24:00 – "bed time") + (00:00 + "out of bed")) = sleep duration

This yielded 12 different sleep durations ranging from 6.25 to 12.25 hrs/night in 9-year olds and 11 different sleep durations ranging from 5.75 to 10.75 hrs/night in 15-year olds.

3.4.6 Screen time

The participants self-reported how many hours they usually watched TV before and after school, and how many hours they usually spent in front of a computer or with a videogame on weekdays (Appendix 5). We combined this information to estimate total screen time on weekdays **(Paper IV)**. By using the halfway point in the second-lowest to second-highest categories and by adding 0.5 hour to the highest category, we approximated total screen time on a numeric, continuous scale by summing the values from the three questions. This yielded 17 and 18 different screen times ranging from zero to 9.5 hrs/d in 9-year olds and 15-year olds, respectively.

3.4.7 Active school transport

The participants self-reported their usual transport mode and time to school (Appendix 5). In **Paper IV**, we categorized the participants into three categories: 1) participants indicating a passive (car, motorcycle, buss, tram, metro, train) or active transport to school (walked, cycled) time of ≤ 5 min/d, 2), participants indicating an active transport time of 6-15 min/d, and 3) participants indicating an active transport time of ≥ 16 min/d.

3.4.8 Sports participation

The participants indicated zero, 1-2, 3-4, 5-7, 8-11 or ≥ 11 hours per week of doing sports/exercise outside of school making them sweat or breathe hard (Appendix 5). Because of a limited number of participants in each category, we chose to combine the lowest two categories, the middle two categories and the upper two categories into three categories in **Paper IV**: 1) ≤ 2 hrs/week, 2) 3-7 hrs/week and 3) ≥ 8 hrs/week.

3.4.9 Measurement month/season and daylight

Norway is located far north in the northern hemisphere, and there are large seasonal variations in climate and hours of daylight. We therefore included season (spring: March-May, summer: June-August, fall: September-November, winter: December-February) and measurement month as covariates in the analyses in **Paper I and III**, respectively. For **Paper IV**, we downloaded hours of daylight for all the start dates of accelerometer measurements from https://www.timeanddate.com/sun/norway, and included daylight (continuous) as a covariate in the analyses.

3.5 Statistics

We performed all the statistical analyses using Stata 13.1 (StataCorp. 2013. Stata Statistical Software: TX: StataCorp LP.). A two-tailed alpha level of 0.05 was used for statistical significance, and was adjusted for multiple comparison where appropriate.

3.5.1 Paper I

Secular changes

We analyzed differences in age and anthropometrics between participants in PANCS1 and 2 and differences in PA and ST between girls and boys within the two cohorts, using generalized linear models (GLM). We adjusted the GLMs used to analyze sex differences in ST, LPA, and MVPA for accelerometer wear time. Differences in the proportions of participants meeting PA guidelines between PANCS1 and 2 and between girls and boys within the two cohorts were analyzed using logistic regression (logit). Differences in SES between participants in PANCS1 and 2 were analyzed using ordered logistic regression (ologit). For the main analyses of secular changes in overall PA, ST, LPA, and MVPA between PANCS1 and 2, we used GLMs adjusted for age, measurement month, and SES. Generalized linear models used to analyze secular changes in ST, LPA, and

MVPA were also adjusted for accelerometer wear time. To obtain standard errors robust against the clustered nature of the study samples, we included school as a cluster variable in all analyzes using the vce(cluster) option.

Longitudinal changes

We analyzed sex differences at baseline and follow-up using random effects linear models (xtreg) and random-effects logit models (xtlogit). We used the same models to study baseline differences between the included study sample and those lost to follow-up. To analyze loss to follow-up differences in baseline SES, we used random effects ordered logistic models (xtologit).

We analyzed longitudinal changes using random effects linear models (xtreg, continuous outcomes) and conditional logistic regression (clogit, categorical outcomes) with age as a binary predictor variable. We adjusted for accelerometer wear time (with the exception of analyses with CPM as the outcome variable), SES, season at both assessment points, and number of days between PA assessments. To obtain standard errors robust against the clustered nature of the study samples, we included baseline school as a cluster variable in all analyses using the vce(cluster) option. To investigate whether changes from age nine to 15 were different in boys and girls, we included the two-way interaction term sex*age in the models.

To assess tracking of the continuous PA variables from age nine to 15, we categorized the participants into variable-specific quintiles and calculated Spearman's rank correlation coefficients. To assess whether the odds of meeting the Norwegian PA recommendations at age 15 were different between those that met and did not meet the recommendations at age , we used random effects logit models (xtlogit).

3.5.2 Paper II

For the cross-sectional analyses, we included 6-year-olds from PANCS2 and 9- and 15-year-olds from both PANCS1 and 2. Those included in the analytical sample had measures of BMI and/or WC, and ≥2 valid days of PA recordings. For the prospective analyses, we included participants with ≥2 valid days of PA recordings at baseline and measures of BMI and/or WC at both baseline and follow-up.

We analyzed sex differences, differences between age groups, changes from age nine to 15 years and associations between PA, BMI and WC using random effects linear (xtreg) and random-effects logit models (xtlogit), with school declared as the panel (xtset). School was included as a cluster variable in all models using the vce(cluster) option to obtain standard errors robust against the clustered nature of the study samples.

To quantify the cross-sectional and prospective associations between PA of different intensities (LPA, MPA and VPA), BMI and WC, we used isotemporal substitution modelling [179]. In isotemporal substitution modelling, all quantifiable components of a behavior are entered into the model simultaneously, together with the sum of all components, except for the component to be substituted. In the present study, summing time spent in all components of PA (ST + LPA + MPA + VPA = accelerometer wear time) renders time isotemporal (constant). By excluding ST from the model, but keeping accelerometer wear time, the beta coefficients for LPA, MPA and VPA represent the theoretical effect of displacing a fixed duration of ST with a fixed duration of LPA, MPA and VPA, respectively [184, 185]. To obtain beta coefficients representing 10 min d^{-1} substitutions, we multiplied each component of PA by a constant of 0.1 before entering them into the models. We entered the dependent (BMI and WC) and independent (LPA, MPA, and VPA) variables into the models in their continuous form.

In initial analyses, we included sex by PA component (LPA, MPA, VPA) interaction-terms to assess whether any of the associations were modified by sex. This yielded significant sex by MPA interactions among 6-year olds ($p \leq 0.039$). No interactions were found in the remainder of analyses. Consequently, we stratified analyses of 6-year olds by sex, whereas all other analyses were performed combining girls and boys, but adjusting for sex. All the main analyses were additionally adjusted for age (continuous). In addition, we adjusted the prospective analyses for the baseline value of the outcome (BMI/WC) and follow-up time. Socioeconomic status was included as a covariate in preliminary analyses; however because inclusion of this variable did not alter the results to any appreciable extent, it was excluded from our final models.

Lastly, we tested for multicollinearity using the correlate (pairwise correlation) and collin (variance inflation factors and tolerance statistics) commands. Because the highest observed correlation was below 0.8 (highest observed, $r = 0.53$), the mean variance inflation factor was below 6 (highest observed mean = 1.39), the highest individual variance inflation factor was smaller than 10 (highest observed = 1.59), and the tolerance statistic was larger than 0.1 (all observed to be > 0.62), there was no indication of multicollinearity.

3.5.3 Paper III

We used an independent samples t-test to investigate sex differences and one-way ANOVA to assess differences between age groups. For the main analyses, we used random effects linear models (xtreg) with school declared as panel (xtset), adjusting the standard errors for the clustered nature of the data using the vce(robust) option. In initial analyses, we included interaction terms to check if any of the associations were modified by sex. Because none of the interaction terms was statistically significant ($p \geq 0.151$), we analyzed girls and boys together, but adjusted for sex. All the main analyses were additionally adjusted for accelerometer wear time (except analyses with CPM as the dependent variable), measurement month, SES, and the dummy variables “access to areas outside school property”, “sectioning of play areas”, “recess at different time points for different classes”, and “allowed to spend recess indoors”. In analyses with the size of schools’ outdoor areas as the dependent variable, we also adjusted for number of permanent play facilities. Collinearity between the variables in the models was checked using *correlate*. All of the pairwise correlations were below 0.56.

3.5.4 Paper IV

For the cross-sectional analyses, we pooled data from PANCS1 and 2 on 9- and 15-year olds. Those included in the analytical sample had measures of one or more of the independent variables and ≥ 2 valid weekdays of PA recordings. For the prospective analyses, we included participants with ≥ 2 valid weekdays of PA recordings at baseline (age nine) and follow-up (age 15) and measures of at least one of the predictor variables at baseline.

We analyzed the cross-sectional associations between MVPA (dependent variable) and the independent variables (sleep, screen time, school transport mode, and sports/exercise) at age nine and 15 using random effects linear regression (xtreg), adjusted for accelerometer wear time, sex, BMI, SES, and minutes of daylight. The prospective associations between changes in MVPA from baseline to follow-up and predictor variables (baseline sleep, baseline screen time, baseline school transport mode, and baseline sports/exercise), were also analyzed using random effects linear regression (xtreg), adjusted for accelerometer wear time, baseline MVPA, sex, baseline BMI, baseline SES, and change in minutes of daylight between baseline and follow-up. In both the cross-sectional and prospective analyses, we declared school as the panel (xtset) and included school as a cluster variable using the vce(cluster) option to obtain standard errors robust against the clustered nature of the study samples.

Since there were more than five sleep and screen time durations and reasonably large sample sizes and the sleep and screen time data were normally distributed, we chose to treat sleep and screen time as a continuous variables [249].

Lastly, we included interaction terms in initial analyses to assess whether sex modified associations. In analyses where the interaction term had a p-value less than 0.1, we stratified the analyses by sex to investigate to what extent sex was a modifier.

4. Results

This chapter presents the main results from each of the four papers.

4.1 Characteristics of the cross-sectional study samples (Papers I-IV)

Table 6 shows characteristics of the cross-sectional study samples in PANCS1 and PANCS2. The 9- and 15-year-old participants in PANCS1 were somewhat older compared to their peers in PANCS2 ($p \leq 0.041$). Nine-year-old boys in PANCS1 were taller and had a slightly lower BMI than 9-year-old boys in PANCS2 ($p \leq 0.044$). In addition, both 9-year-old boys and girls had a significantly larger WC in PANCS1 than in PANCS2 ($p < 0.001$). The 15-year olds in PANCS1 were in excess of five months older than the 15-year olds in PANCS2. Further, the 15-year olds in PANCS1 were taller and had larger WC than their peers in PANCS2 ($p \leq 0.009$). Significant differences between the 15-year-old cohorts were also found for bodyweight (boys, $p = 0.004$) and the prevalence of overweight (girls, $p \leq 0.018$). The participants' socioeconomic status did not differ between PANCS1 and PANCS2, neither between the 9- nor 15-year-old cohorts ($p \leq 0.116$).

Table 6 also shows crude mean values (standard error (SE)) of overall PA, ST, LPA, MPA, and VPA for those in the cross-sectional study samples providing ≥ 2 valid days of PA assessment. Of the 1,306 9-year olds and 993 15-year olds that consented to participate in PANCS1, 1,127 (86.3%) 9-year olds and 702 (70.7%) 15-year olds provided ≥ 2 valid days of PA assessment. Of the 1,071 6-year olds, 1,421 9-year olds, and 1,106 15-year olds that consented to participate in PANCS2, 1,006 (93.9%) 6-year olds, 1,345 (94.7%) 9-year olds, and 972 (87.9%) 15-year olds provided ≥ 2 valid days of PA assessment. Of those not providing ≥ 2 valid days of PA assessment in PANCS1, 25% (n = 118) provided ≤ 1 days of PA assessment, 36% (n = 169) did not wear the monitor at all, and 39% (n = 183) wore a monitor that malfunctioned. Of those not providing ≥ 2 valid days of PA assessment in PANCS2, 66.5% (n = 183) provided ≤ 1 days of PA assessment, 29.8% (n = 82) did not wear the monitor at all, and 3.6% (n = 10) wore a monitor that malfunctioned.

Table 6. Characteristics of the cross-sectional study samples in PANCS1 and PANCS2. Age, Anthropometrics and SES are based on all available data (mean±SD unless otherwise specified). The five PA variables are based on participants with ≥ 2 valid days of accelerometer data (mean (robust SE)).

	6-year olds		**9-year olds**				**15-year olds**			
	Girls	**Boys**	**Girls**	**Girls**	**Boys**	**Boys**	**Girls**	**Girls**	**Boys**	**Boys**
	PANCS2	**PANCS2**	**PANCS1**	**PANCS2**	**PANCS1**	**PANCS2**	**PANCS1**	**PANCS2**	**PANCS1**	**PANCS2**
n[a]	*528-545*	*504-526*	*544-603*	*708-724*	*620-703*	*666-697*	*377-480*	*456-541*	*338-513*	*504-565*
Age (years)	6.6±0.5	6.6±0.4	9.60±0.39	9.55±0.42*	9.63±0.38	9.57±0.44*	15.60±0.37	15.18±0.61*	15.65±0.37	15.19±0.60*
Height (cm)	120.8±5.5	122.0±5.9	138.3±6.8	138.0±6.5	139.9±6.3	138.7±6.8*	165.9±6.2	164.9±6.2*	175.8±7.2	173.2±7.9*
Weight (cm)	23.8±4.5	23.9±3.7	33.8±7.1	33.8±6.8	34.0±6.5	34.0±7.0	58.3±8.9	57.3±9.5	64.6±12.1	62.4±11.9*
BMI (kg/m2)	16.2±2.1	16.0±1.6	17.5±2.7	17.6±2.7	17.3±2.5	17.6±2.8*	21.2±2.9	21.1±3.1	20.8±3.4	20.7±3.3
WC (cm)	54.5±5.1	54.7±4.2	63.1±7.7	59.5±6.6*	62.1±7.3	60.7±7.1*	73.4±7.3	69.1±6.7*	75.0±8.9	73.2±8.5*
OW (%)[b]	18.2/22.9	12.4/20.2	20.1/25.2	23.4/28.5	16.5/23.0	18.9/28.5*	16.1/14.0	23.0*/19.8*	11.8/15.8	14.0/20.0
Obese (%)[b]	4.3/5.6	2.5/4.1	4.7/6.3	3.9/6.3	3.5/7.4	5.7*/9.4	1.7/1.3	3.5/3.1	4.0/6.0	2.6/5.1
SES, Low (%)	5.8	5.6	6.4	8.0	8.9	6.2	5.0	6.3	6.2	8.0
SES, Middle (%)	33.0	33.9	40.8	36.7	35.7	39.3	41.6	40.7	35.2	38.5
SES, High (%)	61.2	60.5	52.8	55.3	55.5	54.6	53.3	53.1	58.6	53.5
n[c]	*512*	*494*	*526*	*693*	*601*	*652*	*361*	*489*	*341*	*483*
Overall PA (cpm)[d]	730 (16.9)	815 (17.8)	682 (24.8)	585 (15.2)	785 (20.8)	697 (19.2)	470 (17.6)	418 (10.3)	527 (17.3)	487 (12.9)
ST (min/d)[e]	396 (2.4)	375 (2.7)	431 (3.1)	472 (2.8)	410 (3.8)	451 (3.4)	546 (3.9)	582 (2.2)	535 (5.0)	561 (4.0)
LPA (min/d)[e]	253 (1.5)	256 (1.8)	266 (2.2)	229 (1.7)	269 (2.5)	230 (1.7)	193 (2.8)	152 (1.8)	198 (3.8)	165 (2.8)
MPA (min/d)[e]	74 (1.1)	92 (1.5)	66 (1.5)	65 (1.2)	82 (1.9)	82 (1.8)	54 (2.2)	53 (1.6)	57 (2.1)	59 (1.7)
VPA (min/d)[e]	8 (0.4)	8 (0.4)	9 (0.5)	6 (0.3)	12 (0.5)	7 (0.4)	7 (0.6)	5 (0.3)	10 (0.7)	8 (0.4)

BMI, body mass index. OW, overweight. SES, socioeconomic status. ST, sedentary time. LPA, light PA. MPA, moderate PA. VPA, vigorous PA. [a] The n varies between variables. the n is lowest for SES in PANCS1 and waist circumference (wc) in PANCS2. [b] Based on age- and sex-specific BMI cut-points from the IOTF (left) and the WHO (right) (OW includes Obese) [242, 243]. [c] Participants with ≥ 2 valid days of accelerometer data [d] Standard errors (SE) adjusted for cluster sampling. [e] Standard errors (SE) adjusted for cluster sampling, mean values adjusted for accelerometer wear time. * Value significantly different from values in PANCS1 ($p \leq 0.049$).

4.2 Characteristics of the prospective study sample (Papers I, II, IV)

Table 7 shows characteristics of the sub-sample of participants partaking in both PANCS1 at age nine and in PANCS2 at age 15. The mean±SD interval between baseline and follow-up assessments was 5.6±0.5 years, ranging from 4.7 to 6.9 years. Of note is that the age-standardized prevalence of overweight increased significantly from baseline to follow-up among girls (p = 0.029), whereas the age-standardized prevalence of obesity decreased significantly from baseline to follow-up among boys ($p \leq 0.026$).

Table 7. Characteristics at baseline and follow-up in the prospective study sample, based on all available data (mean±SD unless otherwise specified). The five PA variables are based on participants with ≥ 2 valid days of accelerometer data at both baseline (PANCS1) and follow-up (PANCS2) (mean (robust SE)).

	Girls		**Boys**	
	PANCS1	**PANCS2**	**PANCS1**	**PANCS2**
n[a]	318-354	283-354	341-377	324-377
Age (years)	9.6±0.4	15.2±0.6	9.6±0.4	15.2±0.6
Height (cm)	138.1±165.1	165.1±6.1	139.9±6.1	173.9±8.0
Weight (cm)	33.1±6.7	57.3±9.4	33.7±6.3	62.1±11.2
BMI (kg/m^2)	17.2±2.6	21.0±3.0*	17.1±2.4	20.5±3.0*
WC (cm)	62.2±7.1	68.6±6.2	61.6±7.2	72.8±8.0
OW (%)[b]	17.4/22.6	22.5*/19.5	14.1/20.8	11.9/17.4
Obese (%)[b]	2.9/4.0	2.9/2.6	2.9/6.4	1.5*/3.5*
SES, Low (%)	5.4	5.2	8.5	6.4
SES, Middle (%)	41.8	37.5	39.6	36.2
SES, High (%)	52.8	57.3	51.9	57.4
n[c]	272	272	286	286
Overall PA (cpm)[d]	691 (27.2)	431 (12.3)	775 (22.6)	511 (12.3)
ST (min/d)[e]	433 (4.0)	573 (3.2)	419 (4.2)	554 (3.8)
LPA (min/d)[e]	270 (2.8)	150 (3.0)	274 (3.2)	166 (3.0)
MPA (min/d)[e]	68 (1.8)	54 (2.0)	85 (2.2)	62 (1.6)
VPA (min/d)[e]	10 (0.5)	5 (0.4)	11 (0.6)	9 (0.4)

BMI, body mass index. OW, overweight. SES, socioeconomic status. [a] The n varies between variables; the n is lowest for SES in PANCS1 and for WC in PANCS2. [b] Based on age- and sex-specific BMI cut-points from the IOTF (left) and the WHO (right), OW includes obese [242, 243]. [c] Participants with ≥ 2 valid days of accelerometer data at both baseline (PANCS1) and follow-up (PANCS2). [d] Standard errors (SE) adjusted for cluster sampling. [e] Standard errors (SE) adjusted for cluster sampling, mean values adjusted for accelerometer wear time. *Significant change from PANCS1 ($p \leq 0.029$).

4.2.1 Loss to follow-up

Table 8 shows descriptive characteristics and assessments of those included in the prospective study sample and participants that were lost to follow-up, relevant to **Papers I, II, and/or IV**. Compared to those lost to follow-up, girls and boys in the prospective study sample had lower BMI and WC at baseline. In addition, a lower proportion of those included in the prospective study sample were categorized as overweight or obese. Overall PA, ST, and LPA did not differ between the two groups, but girls in the prospective study sample did spend significantly more time in MVPA at baseline compared to their peers that were lost to follow-up. Girls in the prospective study sample also reported less screen time than girls lost to follow-up. Boys in the prospective study sample reported sleeping more and spending more time playing sports or exercising than those who were lost to follow-up. We did not find significant differences between the prospective study sample and those lost to follow up in terms of SES or active transport to school.

*Table 8. Comparisons of baseline characteristics and assessments between the prospective study samples included in **Papers I, II, and IV** and those lost to follow-up.*

	Girls		**Boys**	
	Study sample[a]	**Lost to FU**	**Study sample[a]**	**Lost to FU**
n[b]	249-272	254-331	260-286	317-414
Age (years)	9.6±0.4	9.6±0.4	9.7±0.4	9.6±0.4
BMI (kg·m^{-2})	17.3±2.6*	17.7±2.8	17.0±2.1*	17.4±2.7
WC (cm)	62.2±7.0*	63.9±8.2	61.3±6.6*	62.7±7.7
Overweight (%)[c]	15.9*/22.1	23.7/27.7	13.3/19.3	18.7/25.6
Obese (%)[c]	3.3/4.1*	5.9/8.1	1.8*/4.6*	4.7/9.4
SES, Low (%)	4.8	7.8	7.7	9.7
SES, Middle (%)	39.4	42.0	39.2	33.1
SES, High (%)	55.8	50.2	53.1	57.2
Overall PA (CPM)	691±238	671±260	775±255	794±295
ST (min/d)	426±64	429±62	417±70	410±69
LPA (min/d)	267±41	263±41	273±49	267±45
MVPA (min/d)	77±23*	73±22	96±30	93±31
Sleep (hrs/d)	10.29±0.53	10.25±0.61	10.36±0.61*	10.26±0.58
Screen time (hrs/d)	2.10±1.25*	2.33±1.31	2.80±1.34	2.93±1.50
Active transport				
0-5 min/d (%)	36.4	41.6	39.5	42.7
6-15 min/d (%)	39.9	38.9	41.4	37.0
≥ 16 min/d (%)	23.6	19.5	19.2	20.3
Sports/exercise				
≤ 2 hrs/week (%)	40.9	45.8	21.4	31.5
3-7 hrs/week (%)	50.6	47.8	60.5*	53.2
≥ 8 hrs/week (%)	8.5	6.4	18.1*	15.3

FU, follow-up; BMI, body mass index; WC, waist circumference; SES, socioeconomic status; hrs/d, hours per day; min/d, minutes per day. Active transport, walking or cycling to school. [a] Those with ≥ 2 valid days of accelerometer data at both baseline (age nine) and follow-up (age 15). [b] The n varies between variables; the n is lowest for SES in the study sample groups and for the PA variables in the loss to follow-up groups. [c] Based on age- and sex-specific BMI cut-points from the IOTF (left) and the WHO (right), OW includes Obese [242, 243]. * Significantly different at baseline from those lost to follow-up ($p \leq 0.047$).

4.3 Paper I

4.3.1 Secular changes in physical activity

Table 9 shows adjusted overall PA levels and time spent sedentary, in LPA, and in MVPA by age group, sex, and study year, as well as adjusted secular changes between 2005/06 and 2011/12. At both time points, girls had a significantly lower overall PA level than boys within the same age group ($p < 0.001$). This resulted from girls spending more time sedentary and less time in MVPA ($p \leq 0.030$). In 2011/12, 15-year-old girls also spent significantly less time in LPA compared to 15-year-old boys ($p < 0.001$).

Table 9. Mean (SE) physical activity levels in 2005/06 and 2011/12 and secular change from 2005/06 to 2011/12 (mean difference (95% CI)).

	2005/06[a]	**2011/12**[a]	**mean difference (95% CI)**[a]	***p***
9-year-old girls	*n = 479*	*n = 676*		
Overall PA (CPM)	677 (20.6)	589 (11.3)	-87.8 (-134.6, -41.0)	< 0.001
ST (min/d)	430 (3.3)	470 (2.2)	40.4 (32.2, 48.5)	< 0.001
LPA (min/d)	264 (2.2)	229 (1.6)	-35.6 (-41.2, -29.9)	< 0.001
MVPA (min/d)	75 (1.6)	71 (1.1)	-4.2 (-8.2, -0.2)	0.041
9-year-old boys	*n = 532*	*n = 641*		
Overall PA (CPM)	778 (17.1)*	708 (13.3)*	-69.6 (-113.5, -25.7)	0.002
ST (min/d)	413 (3.4)	451 (3.0)	38.3 (28.8, 47.8)	< 0.001
LPA (min/d)	267 (2.5)*	232 (1.8)*	-35.2 (-41.9, -28.5)	< 0.001
MVPA (min/d)	94 (2.1)*	91 (1.6)*	-2.9 (-8.3, 2.4)	0.284
15-year-old girls [b]	*n = 291*	*n = 476*		
Overall PA (CPM)	468 (10.3)	421 (8.4)	-47.1 (-71.7, -22.6)	< 0.001
ST (min/d)	538 (3.5)	587 (2.3)	48.9 (39.3, 58.6)#	< 0.001
LPA (min/d)	197 (3.1)	150 (1.7)	-47.1 (-55.6, -38.7)#	< 0.001
MVPA (min/d)	61 (1.6)	59 (1.5)	-1.5 (-5.9, 2.8)	0.487
15-year-old boys [b]	*n = 255*	*n = 463*		
Overall PA (CPM)	522 (19.9)*	490 (14.0)*	-31.9 (-90.3, 26.4)	0.284
ST (min/d)	531 (5.4)	566 (3.7)	35.7 (19.8, 51.6)#	< 0.001
LPA (min/d)	203 (3.5)*	164 (2.2)*	-38.6 (-48.3, -28.9)#	< 0.001
MVPA (min/d)	65 (2.7)*	68 (2.0)*	3.4 (-4.5, 11.3)	0.394

[a] Adjusted for cluster sampling, accelerometer wear time (except in analyses of CPM), age, season, SES. [b] Additionally adjusted for follow-up status (participation at both age nine and 15). * Significantly different from girls within same study year ($p \leq 0.030$). # Secular change significantly different between girls and boys ($p \leq 0.050$).

The overall PA level of 9-year-old girls and boys was significantly lower in 2011/12 compared to 2005/06 ($p \leq 0.002$). Nine-year-old girls and boys recorded 13.0% and 9.0% less cpm in 2011/12 than in 2005/06. Further, 9-year-old girls and boys spent significantly more time sedentary (~9%) and less time in LPA (~13%) in 2011/12 compared to 2005/06. Nine-year-old girls in the 2011/12 cohort also spent 5.6% less time in MVPA compared to their peers in the 2005/06 cohort. For boys, time spent in MVPA did not differ between the 2005/06 cohort and the 2011/12 cohort.

Fifteen-year-old girls in the 2011/12 cohort recorded significantly less cpm compared to 15-year-old girls in the 2005/06 cohort, with the difference translating to 10.1%. In contrast, the overall PA level among 15-year-old boys did not differ significantly between the participants in the two cohorts ($p = 0.284$). We observed secular changes in ST and LPA among both 15-year-old girls and boys, but the size of the secular changes were significantly bigger in girls compared to boys. Fifteen-year-old girls in the 2011/12 cohort spent 9.1% more time sedentary and 23.9% less time in LPA compared to 15-year-old girls in 2005/06. Fifteen-year-old boys spent 6.7% more time sedentary and 19.0% less time in LPA compared to 15-year-old boys in 2005/06. Time spent in MVPA did not differ between 2005/06 and 2011/12, neither among 15-year-old girls, nor among 15-year-old boys ($p \geq 0.394$).

Figure 4 shows the proportion of girls and boys in the two age groups adhering to the Norwegian PA recommendation in 2005/06 and 2011/12. The proportion of girls and boys in the two age groups spending an average of ≥ 60 min/d of MVPA did not differ significantly between 2005/06 and 2011/12.

Figure 4: Proportion of participants spending ≥ 60 minutes per day in MVPA in 2005/06 and 2011/12. Error bars display 95% confidence intervals.

4.3.2 Longitudinal changes in physical activity

Table 10 shows the prospective study samples level of PA and time spent sedentary at age nine and 15 and the absolute changes observed between age nine and 15. At both time points, boys spent significantly less time sedentary and more time in MVPA compared to girls ($p < 0.001$). However, due to a larger absolute decrease in MVPA in boys, the difference in MVPA had decreased between boys and girls at age 15. On the other hand, because the decrease in LPA was larger in girls than in boys, the difference in LPA between boys and girls went from non-significant at age nine (p = 0.731) to significant at age 15 (p < 0.001).

Table 10: Mean (SE) PA level among girls (n = 272) and boys (n = 286) providing valid PA data at both age nine and 15 and longitudinal changes (mean change (95% CI)).

		Age 9[a]	Age 15[a]	mean change (95% CI)[a]	p
Girls		n = 272	n = 272		
	Overall PA (CPM)	713 (24.1)	414 (10.7)	-298.5 (-346.1, -250.8)	< 0.001
	Sedentary (min/d)	432 (4.0)	574 (2.8)	142.2 (134.5, 149.8)	< 0.001
	LPA (min/d)	269 (2.9)	150 (2.5)	-119.2 (-125.7, -112.6)	< 0.001
	MVPA (min/d)	79 (1.9)	59 (1.9)	-20.8 (-24.9, -16.6)	< 0.001
Boys		n=286	n=286		
	Overall PA (CPM)	791 (23.6)*	503 (14.6)*	-287.8 (-349.7, -225.9)	< 0.001
	Sedentary (min/d)	417 (4.8)*	554 (3.8)*	136.6 (123.4, 149.7)	< 0.001
	LPA (min/d)	273 (3.7)	166 (2.5)*	-106.7 (-116.4, -97.1)#	< 0.001
	MVPA (min/d)	98 (2.8)*	70 (1.9)*	-27.8 (-34.3, -21.2)#	< 0.001

[a] Adjusted for cluster sampling (SE), SES, season, accelerometer wear time (except in analyses of CPM), and days between accelerometer measurements. * Significantly different from girls within age group ($p \leq 0.001$). # Change significantly different from girls ($p \leq 0.027$). PA, physical activity; CPM, counts per minute; LPA, light physical activity; MVPA, moderate-to-vigorous physical activity; min/d, minutes per day.

Figure 5 shows relative changes in overall PA, ST, LPA and MVPA between age nine and 15. Overall PA decreased and sedentary time increased by more than 30% in both girls and boys over the six-year period. In girls, LPA and MVPA decreased by 44% and 26%, respectively. In boys, the corresponding decreases were 39% in LPA and 28% in MVPA.

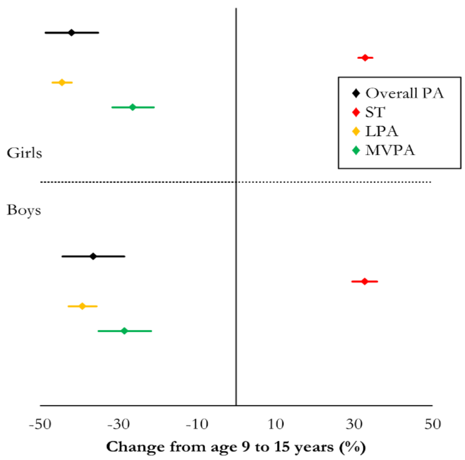

Figure 5: Mean (95% CI) longitudinal changes (%) in overall PA, time spent sedentary (ST), in LPA and in MVPA at age nine to 15.

From age nine to 15, the proportion of girls meeting the Norwegian PA recommendations of ≥ 60 min/d of MVPA fell from 76% to 48%. Among boys, the proportion fell from 92% at age nine years to 62% at age 15 (Figure 6).

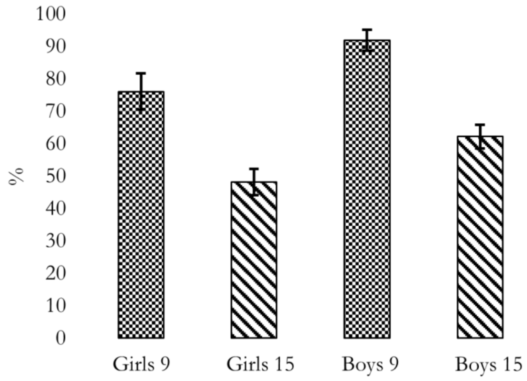

Figure 6: Proportions spending ≥ 60 minutes per day in MVPA at age nine and 15. Error bars display 95% confidence intervals.

Spearman's correlation coefficients between measures of PA at age nine and 15 were significantly greater than zero ($p \leq 0.012$), ranging from 0.15 (ST in boys) to 0.35 (overall PA in girls). The odds of achieving an average of ≥ 60 min/d of MVPA at age 15 were 3.4 and 3.8 times higher among the girls (95% CI: 2.0, 5.8) and boys (95% CI: 2.4, 6.0) who met this recommended level at age nine, respectively, ($p < 0.001$). At age 15, 56% of the girls and 65% of the boys who met the Norwegian PA recommendations at age nine also did so at age 15.

4.4 Paper II

4.4.1 Cross-sectional associations between physical activity, waist circumference, and body mass index

Table 11 shows the results from isotemporal substitution of 10 min/d of ST with 10 min/d of light, moderate, and vigorous intensity PA on WC and BMI. Because sex significantly modified the associations between substitutions of ST with MPA and both outcome variables in 6-year olds ($p \leq 0.039$), we stratified the cross-sectional analysis of 6-year olds by sex. We did not find other interaction by sex and therefore present the results for 9- and 15-year-old girls and boys combined, but adjusted for sex.

Table 11: Cross-sectional associations between 10 min/day substitutions of ST, BMI and WC [a].

Replacing 10 min/d^{-1} of sedentary time with 10 min/d^{-1} of:	n	Body mass index (BMI) (kg·m^{-2}) β (95% CI)	n	Waist circumference (WC) (cm) β (95% CI)
6-year-old girls	505		495	
Light PA		0.10 (0.04, 0.17)**		0.29 (0.13, 0.45)**
Moderate PA		-0.18 (-0.35, -0.01)*		-0.47 (-0.85, -0.10)*
Vigorous PA		-0.21 (-0.58, 0.16)		-0.15 (-1.20, 0.90)
6-year-old boys	485		475	
Light PA		0.08 (0.02, 0.15)*		0.15 (-0.02, 0.33)
Moderate PA		0.03 (-0.05, 0.12)		0.06 (-0.16, 0.29)
Vigorous PA		-0.32 (-0.71, 0.06)		-0.79 (-1.68, 0.10)
9-year-olds	2,445		2,423	
Light PA		0.05 (0.02, 0.07)**		0.17 (0.10, 0.25)**
Moderate PA		-0.08 (-0.15, -0.02)*		-0.32 (-0.46, -0.18)**
Vigorous PA		-0.83 (1.04, -0.63)**		-1.79 (-2.36, -1.23)**
15-year-olds	1,592		1,544	
Light PA		0.03 (-0.02, 0.07)		0.17 (0.06, 0.28)**
Moderate PA		0.06 (-0.02, 0.15)		0.02 (-0.20, 0.24)
Vigorous PA		-0.56 (-0.87, -0.25)**		-1.08 (-1.94, -0.21)*

[a] Adjusted for sex (not in analyses of 6-year olds), age, and accelerometer wear time. *$p \leq 0.040$, ** $p \leq 0.003$. CI, confidence interval; PA, physical activity.

Waist circumference: Substituting 10 min/d of ST with 10 min/d of LPA was associated with a slightly larger WC in 6-year-old girls and in 9- and 15-year olds ($p \leq 0.002$). Substituting 10 min/d of ST with 10 min/d of LPA was not significantly associated with WC in 6-year-old boys. In 6-year-old girls and 9-year olds, substituting ST with MPA was associated with a smaller WC, ($p \leq 0.013$). Substitution of ST with MPA was not associated with WC in the other age or sex groups. Substituting ST with VPA was associated with smaller a WC in 9-year olds and 15-year olds ($p \leq 0.015$), but not in 6-year olds.

Body mass index: Substitution of ST with LPA was associated with a higher BMI in 6-year-old girls, 6-year-old boys, and in 9-year olds ($p \leq 0.012$). Substitution of ST with LPA was not associated with BMI in 15-year olds. Substitution of ST with MPA was associated with a lower BMI in 6-year-old girls and in 9-year olds ($p \leq 0.034$), but was not associated with BMI in 6-year-old boys or 15-year olds. Substitution of ST with VPA was associated with a lower BMI in both 9- and 15-year olds ($p < 0.001$), but not in 6-year olds.

4.4.2 Prospective associations between physical activity, waist circumference, and body mass index

In both girls and boys, changes in BMI and WC from age nine to 15 were accompanied by significant increases in ST and significant decreases in LPA, MPA, and VPA ($p < 0.001$). However, results from the prospective analyses did not indicate that reallocation of time spent sedentary to LPA, MPA, or VPA at age nine predicted BMI ($p \geq 0.059$) or WC ($p \geq 0.321$) six years later (Table 12).

Table 12: Prospective associations between 10 min/day substitutions of ST, BMI, and WC [a].

Replacing 10 min/d^{-1} of sedentary time with 10 min/d^{-1} of:	**n**	**Body mass index (BMI) (kg·m^{-2}) β (95% CI)**	**n**	**Waist circumference (WC) (cm) β (95% CI)**
Light PA	503	0.05 (-0.00, 0.11)	476	0.07 (-0.08, 0.23)
Moderate PA	503	-0.05 (-0.14, 0.04)	476	-0.09 (-0.37, 0.20)
Vigorous PA	503	0.16 (-0.17, 0.49)	476	-0.43 (-1.29, 0.42)

[a] Adjusted for sex, age at baseline, follow-up time, and BMI/WC at baseline. CI, confidence interval; PA, physical activity.

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4.5 Paper III

Because of construction work, we did not get valid assessments of the outdoor play area in three of the 103 included schools in PANCS2. All pupils in these three schools were therefore excluded from the analyses in **Paper III** (n = 212). We also excluded participants that did not provide ≥ 2 valid school days of PA data (n = 346). In total, 968 6-year olds, 1,288 9-year olds, and 784 15-year olds made up the study samples.

4.5.1 Permanent play facilities

We registered more than 50 unique permanent play facilities across the participating schools. The mean (±SD) number of permanent play facilities per pupil in the 6- (0.095±0.055) and 9-year olds' (0.093±0.058) schools was similar and about three times higher than in the 15-year olds' (0.037±0.033) schools ($p < 0.001$).

The number of permanent play facilities per pupil was not associated with overall PA or MVPA in any of the three age groups ($p \geq 0.145$). However, ST and LPA was associated with the availability of permanent play facilities in 6-year olds ($p \leq 0.034$). An increase in permanent play facility availability of 0.1 per pupil (approximately a doubling of the mean availability) was associated with 3.8 min/d (95% CI: -7.3, -0.3) less ST and 2.2 min/d (95% CI: 0.5, 3.8) more LPA. This translates to 3.1% less ST and 2.5% more time spent in LPA during school hours. Availability of permanent play facilities was not associated with ST or LPA in 9- and 15-year olds ($p \geq 0.192$).

4.5.2 The size of schools' outdoor play areas

The size of the schools' outdoor play areas varied considerably, ranging from 4.2 m^2 to 245.6 m^2 per pupil in primary schools and from 4.1 m^2 to 149.8 m^2 per pupil in lower secondary schools. The mean (±SD) sizes of the schools' outdoor play areas were 65.6±45.2 m^2, 62.9±43.0 m^2, and 49.9±35.7 m^2 per pupil for 6-, 9-, and 15-year olds, respectively.

Schools' outdoor play area size was not associated with any of the PA variables or ST in 6- and 9-year olds ($p \geq 0.655$). Among 15-year olds, outdoor play area size was not associated with overall PA or ST ($p \geq 0.295$), but significantly associated with LPA ($p = 0.009$) and MVPA ($p = 0.027$). A 10 m^2 increase in the size of outdoor play area per pupil is associated with 0.9 (95% CI: 0.2, 1.5) more minutes of LPA and 0.4 (95% CI: -0.8, -0.1) less minutes of MVPA per school day.

4.6 Paper IV

Table 13 shows the mean (SD) weekday MVPA, sleep duration, and screen time, as well as the proportions of daily active transport time to school and weekly sports/exercise participation of the samples included in **Paper IV**.

*Table 13: Weekday MVPA, sleep, screen time, and active transport to school and weekly sports/exercise participation in the cross-sectional and prospective study samples included in **Paper IV** (mean (SD) unless otherwise specified).*

	Cross-sectional samples				**Prospective sample**			
	9-year olds	**n**	**15-year olds**	**n**	**Baseline**	**n**	**Follow-up**	**n**
MVPA (min/d)	92.1 (30.6)	2,366	68.6 (26.3)	1,554	98.2 (33.3)	517	69.5 (25.6)	517
Sleep (hrs/d)	9.7 (0.8)	2,102	8.1 (0.9)	1,165	10.3 (0.6)	478	7.5 (0.7)	382
Screen time (hrs/d)	2.6 (1.3)	2,081	3.9 (1.6)	1,209	2.4 (1.3)	476	3.9 (1.6)	399
Active transport								
0-5 min/d	43.7%	926	52.3%	652	38.6%	188	48.9%	204
6-15 min/d	35.8%	757	36.1%	450	40.5%	197	36.7%	153
≥ 16 min/d	20.5%	434	11.6%	1,247	20.9%	102	14.4%	60
Sports/exercise								
≤ 2 hrs/week	36.1%	762	30.2%	373	30.8%	150	28.6%	117
3-7 hrs/week	53.1%	1,119	46.8%	577	56.1%	273	43.8%	179
≥ 8 hrs/week	10.8%	228	23.0%	284	13.1%	64	27.6%	113

SES, socioeconomic status; MVPA, moderate-to-vigorous physical activity on weekdays; hrs/d, hours per day; min/d, minutes per day; hrs/week, hours per week.

4.6.1 Correlates of physical activity

Figure 7 A-D shows the cross-sectional associations between sleep, screen time, active school transport, sport/exercise participation, and weekday MVPA.

Sleep: The mean (±SD) sleep durations reported by the 9- and 15-year olds were 9.7±0.8 and 8.1±0.9 hrs/night, respectively. Among 9-year olds, 83% reported sleeping the recommended minimum or more (≥ 9 hrs/night). Among 15-year olds, the corresponding proportion was 54% (≥ 8 hrs/night). Sleep duration was not associated with MVPA in either age group (Figure 7A), neither when modeled continuously ($p \geq 0.274$), nor when dichotomized based on recommended sleep durations ($p \geq 0.241$).

Screen time: The mean (±SD) screen times reported were 2.6±1.3 hrs/d among 9-year olds and 3.9±1.6 hrs/d among 15-year olds. Forty-six percent of 9-year olds and 19% of 15-year olds reported spending ≤ 2 hrs/d in front of a screen. Inverse associations between screen time and MVPA were found in both age groups ($p < 0.001$). Each additional hour of screen time was associated with 2.2 min/d (95% CI: -3.1, -1.3) less MVPA in 9-year olds and 1.7 min/d (95% CI: -2.7, -0.8) less MVPA in 15-year olds (Figure 7B). Dichotomizing screen time based on suggested recommended levels revealed that 9-year olds spending > 2 hrs/d in front of a screen accumulated 4.3 min/d (95% CI: 1.9, 6.8) less MVPA than 9-year-olds spending ≤ 2 hrs/d in front of a screen.

Among 15-year olds, sex modified this association ($p = 0.014$), and the association was only evident among boys (9.9 min/d (95% CI: 3.8, 16.1)).

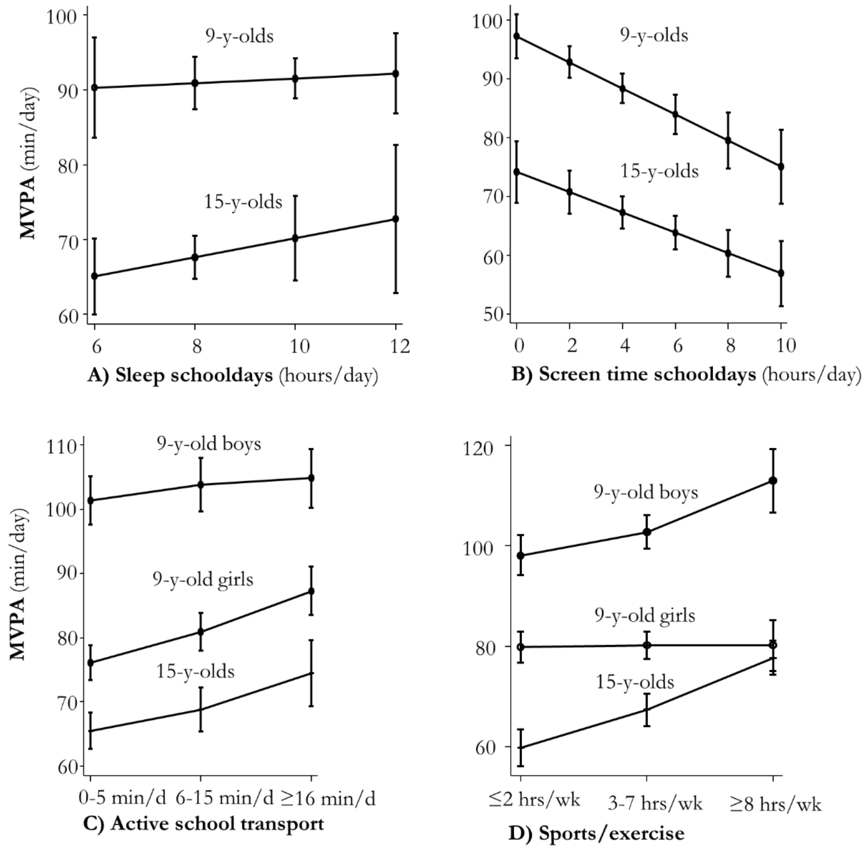

Figure 7: Cross-sectional associations between sleep (A), screen time (B), active school transport (C), sport/exercise participation (D), and MVPA, adjusted for accelerometer wear time, sex, BMI, SES, and daylight. Bars represent 95% confidence intervals.

Active school transport: Active school transport was positively associated with MVPA in both 9- and 15-year olds ($p \leq 0.027$). In 9-year olds, however, the association was modified by sex (p = 0.006). Nine-year-old girls in the high category of active school transport accumulated 10.5 min/d (95% CI: 6.8, 14.3) more MVPA than those in the low category. Nine-year-old girls in the middle category of active school transport accumulated 4.6 min/d (95% CI: 1.5, 7.8) more MVPA than those in the low category (Figure 7C). Among 9-year-old boys, those in the high category of active school transport accumulated 5.0 min/d (95% CI: 0.4, 9.7) more MVPA than those in the low category, but there was no difference in MVPA between those in the middle and low categories. Sex did not modify the association between active school transport and MVPA in 15-year olds and the association appeared dose-dependent (Figure 7C). Compared to 15-year olds in the low category of active school transport, 15-year olds in the middle category accumulated 3.3 min/d (95% CI: 0.4, 6.2) more MVPA. Fifteen-year olds in the high category of active school transport accumulated 9.0 min/d (95% CI: 3.8, 14.1) more MVPA compared to 15-year olds in the low category.

Sports or exercise: Sex significantly modified the association between sport/exercise participation and MVPA in 9-year olds ($p < 0.001$). Whereas 9-year-old boys reporting ≥ 8 hrs/week or 3-7 hrs/week of sports or exercise accumulated significantly more min/d of MVPA than boys reporting ≤ 2 hrs/week, no association between sports/exercise participation and MVPA was observed in 9-year-old girls (Figure 7D). Nine-year-old boys that reported doing 3-7 hrs/week of sports or exercise accumulated 4.5 min/d (95% CI: 0.9, 8.2) more MVPA than boys reporting ≤ 2 hrs/week ($p \leq 0.014$). Nine-year-old boys that reported doing ≥ 8 hrs/week of sports or exercise accumulated 14.7 min/d (95% CI: 8.2, 21.3) more MVPA than boys reporting ≤ 2 hrs/week ($p \leq 0.014$). Among 15-year olds, both girls and boys in the 3-7 and ≥ 8 hrs/week groups accumulated significantly more MVPA than their peers in the ≤ 2 hrs/week group ($p < 0.001$). Fifteen-year olds reporting 3-7 hrs/week of sports or exercise accumulated 7.6 min/d (95% CI: 4.3, 10.8)) more MVPA than 15-year olds reporting ≤ 2 hrs/week. Fifteen-year olds reporting ≥ 8 hrs/week of sports or exercise accumulated 17.9 min/d (95% CI: 14.0, 21.8) more MVPA than 15-year olds reporting ≤ 2 hrs/week.

4.6.2 Determinants of physical activity

From baseline to follow-up, MVPA decreased by an average of almost 30 min/d on weekdays in the prospective study sample. However, none of the four behaviors at baseline were significant predictors of the change in MVPA. Dichotomizing sleep duration and screen time at baseline based on suggested recommendations did not change the results.

5. General discussion

This thesis presents data from two large epidemiological investigations on objectively assessed physical activity in population-based samples of Norwegian children and adolescents. The following general discussion focuses on the main results, study populations, and the strengths and limitations of the studies.

5.1 Secular changes in physical activity

Paper I provides novel information on secular changes in accelerometer assessed PA from the mid-2000s onward in population-based samples of 9- and 15-year olds. The results indicated that PA levels of Norwegian 9-year olds and 15-year-old girls were lower in 2011/12 compared to 2005/06. This was in largely caused by a replacement of time spent in LPA with time spent sedentary. However, the proportion of 9- and 15-year olds meeting the Norwegian PA recommendations did not differ significantly between the two assessment points, although the results indicated that 9-year-old girls in the 2011/12 cohort did spend less time in MVPA compared to their peers in 2005/06.

Compared to the few previous studies investigating secular PA changes using accelerometers [136-138] and pedometers [56, 139, 140], our results may indicate a reversal or halting of the secular increases in PA observed between the late 1990s/early 2000s and the mid-2000s. Similar declines have been observed in Czech adolescents between 1998 and 2010 and in Canadian children and adolescents between 2007 and 2014 [56, 141].

There are several possible explanations to why 9- and 15-year olds might have become less physically active between 2005/06 and 2011/12. It is, however, important to consider whether the observed secular changes are trustworthy or whether they might be caused by methodological differences. In both studies, we used ActiGraph accelerometers to assess PA in population-based samples and we analyzed all the accelerometer data using identical data reduction methods. However, because we used different ActiGraph models in PANCS1 and PANCS2, the results should be interpreted with some caution.

Several studies show that PA data from the newer generations of ActiGraphs, i.e. from the GT1M and forward, can be compared and used interchangeably [250-254]. However, the comparability between the older 7164 model used in PANCS1 and the newer models used in PANCS2 is questionable. Some studies conclude that they yield comparable outputs [244, 255, 256], while others conclude that they do not [250, 252, 257]. The three latter studies observed that overall PA (cpm) was approximately 10% higher when assessed using the 7164 model compared to newer models. Furthermore, they observed that the 7164 model identified less ST, more LPA, and more VPA, whereas MPA outputs were similar between devices. Using close to identical data reduction methods to ours, Grydeland et al. (2014) compared free-living PA data from 16 9-year olds assessed simultaneously with the ActiGraph 7164, GT1M and GT3X+ [250]. The results revealed inter-model differences in cpm equivalent to the secular difference we observed in 9-year olds, suggesting that the different monitors used may account for the secular decline. However, the inter-model differences in ST and LPA observed by Grydeland et al. (2014) were considerably smaller than the secular differences we observed [250].

There is no clear-cut answer to the potential comparability issues between the old and new generation of ActiGraphs. Corder et al. (2007) have suggested using a correction factor to improve the comparability of cpm outputs [257]. However, because the inter-model differences in cpm vary across intensities, this might introduce an unknown bias as it would only apply to similar distributions of time spent across intensities [250]. In addition, the ActiGraph Corporation has tried to address the issue by introducing a low frequency extension option applicable to their newer devices. However, although the low frequency extension option seems to attenuate differences in ST, LPA, and mean cpm, it does not attenuate differences in VPA and in fact introduces a difference in MPA [252]. Because there is no consensus on the comparability between ActiGraph models or, alternatively, on how to improve comparability, we have decided to present our data as is, without any adjustments.

Nevertheless, even if the secular changes we observed may be attributable to the different ActiGraph models used, there is no indication of a secular increase in PA between 2005/06 and 2011/12. In 2005, the Norwegian government launched Norway's first physical activity action plan [258]. The plan outlined more than 100 measures aimed at increasing and strengthening factors that promote PA in the population and reducing the factors that lead to physical inactivity. Even though the action plan identified children and adolescents as target group number one, our results do not indicate that the action plan sufficiently increased PA levels. Given that ~20% of 9-year olds and ~50% of 15-year olds still do not achieve the recommended level of daily MVPA, additional efforts are highly warranted if the Norwegian government wants to fulfill its commitment to reduce physical inactivity by 10% by the year 2025 [11].

In contemporary society, opportunities for sedentary leisure activities seem to be ever increasing among young people. For example, data from the Health Behaviour in School-aged Children Study revealed that in all the 30 participating countries (including Norway), computer use and total screen time increased significantly among 11-, 13-, and 15-year olds from 2002 to 2010 [259]. Further, time use surveys conducted by Vaage et al. (2012) indicate that Norwegian children and adolescents spent more time on education, spent less time with friends, had less time for leisure activities, and spent less time doing sports or scouting activities in 2010 compared to 2000 [260]. These are only a few examples of factors that may influence secular changes in PA. In order to increase PA levels in the years to come, there is a continuing need for studies aiming to untangle the complex nature of PA determinants and to monitor PA on a regular basis.

5.2 Longitudinal changes in physical activity

In **Paper I**, we observed large declines in PA and increases in ST from age nine to 15. The declines in overall PA are considerably larger than the cross-sectional differences between 9- and 15-year olds in both PANCS1 and PANCS2. The mean cross-sectional difference between 9- and 15-year-old girls was 209 cpm in PANCS1 and 168 cpm in PANCS2, compared to a longitudinal decline of 299 cpm. We observed a similar pattern in boys, with cross-sectional differences of 256 cpm in PANCS1 and 218 cpm in PANCS2, compared to a longitudinal decline of 288 cpm. Even if we assume that the longitudinal changes might be overestimated due to the different ActiGraphs used in PANCS1 and 2, this exemplifies how time trends may bias cross-sectional comparisons of PA between different age groups and why longitudinal data are necessary to obtain accurate estimates of changes in PA with age.

A direct comparison of longitudinal changes in accelerometer assessed PA is challenging due to different data cleaning, reduction, and processing procedures across studies. However, it appears that the relative decline in overall PA observed in our study is slightly greater than that observed in Denmark [150], but slightly smaller than that observed in the U.S. and the U.K. [147, 240]. Further, it appears that the relative increase in time spent sedentary is smaller than that observed in samples from the U.S. and Sweden [146, 151]. The observed decline in MVPA in **Paper I** translates to a mean annual MVPA decline of 3.8% among girls and 4.5% among boys. This is two to three times less than declines observed in samples from the U.S. and Sweden [146, 147, 151], but comparable to declines observed in a sample from Norfolk in England. [240].

We observed a larger LPA decline in girls than in boys, but noted that MVPA declines were significantly larger among boys than among girls. This is in line with recently published results from the Gateshead Millennium Cohort Study [149], which do not support the common view that PA declines much more rapidly in adolescent girls than boys.

Although we found that tracking coefficients for all constructs of PA were significantly greater than zero and that the odds of accumulating ≥ 60 min/d of MVPA at age 15 years were > 3 times higher in those accumulating ≥ 60 min/d of MVPA at age nine, the tracking can be considered weak [261]. This may indicate that measures to prevent declines in PA from childhood to adolescence should encompass the entire range of children, not only those with an already low PA level.

5.3 Physical activity and adiposity

The results in **Paper II** revealed favorable, cross-sectional associations between PA of at least moderate intensity and adiposity. This corroborates the results reported by others using isotemporal substitution modeling [181-185]. Although several studies have found beneficial associations between VPA and adiposity in adolescents using other analytical approaches [262], no previous study using isotemporal substitution modeling has modeled substitutions of ST with MPA and VPA separately. In the only other study using isotemporal substitution modeling in an adolescent sample, no association was observed when a substitution of ST with MVPA was modeled [184]. Thus, our results extend previous observations and may support the notion that PA of higher intensity is required to affect the body composition of adolescents compared to children.

The results also revealed somewhat counterintuitive, unfavorable associations when we modeled substitutions of ST with LPA. This is surprising, as others, using both field-based adiposity measurements (BMI, WC) and adiposity measurements that are more comprehensive (DXA), have found either no association [181, 183-185] or a negative association [182] when modeling a substitution of ST with LPA. To our knowledge, only one previous study has reported similar results [263]. Because we did not control for energy intake, this may have confounded the associations. Similarly, energy intake has been suggested to confound associations between TV watching and cardio-metabolic risk factors in children and youth [10, 215, 264]. Furthermore, the classification accuracy of LPA assessed with ActiGraph accelerometers is lower than for ST and MVPA [102], making it possible that some of the time classified as LPA was in fact ST.

Although adiposity has consistently been shown to increase cardio-metabolic risk in children and adolescents [156], limited data on the magnitude of change in cardio-metabolic risk factors associated with absolute incremental change in BMI and WC (i.e. ± 1 kg/m^2 and ± 1 cm) among children and adolescents are available. Hence, it is difficult to translate the observed differences in WC and BMI associated with substitution of ST with MPA and VPA to greater of lesser "clinical" importance. However, because the intra-class correlation coefficient for within-individual differences in accelerometer assessed PA can be as low as 0.5 [265], the true magnitude of the associations may be twice as strong as the associations observed, if we assume that all measurement errors stem from within-individual variability. In addition, the 10 min/d substitutions modeled in **Paper II** are small compared to most previous studies [181, 183-185], and modeling larger substitutions results in stronger associations (Appendix 6). Although the external validity of > 10 min/d VPA substitutions is probably limited at the population level (mean daily VPA was < 10 min/d in all three age groups), > 10 min/d substitutions of ST for MPA may be more achievable. If all Norwegian children and adolescents increased daily MVPA by 10 minutes, the proportions meeting the current PA recommendation would increase from 92% to 97% in 6-year olds, from 80% to 91% in 9-year olds, and from 47% to 64% in 15-year olds.

Although the results from the prospective analyses in **Paper II** agree with the results from some previous studies [10, 169], they contradict the one previous study using isotemporal substitution modeling to study the prospective association between PA and adiposity in children [185]. They also contradict some previous studies using other analytical approaches [70, 266]. This discrepancy may possibly relate to the age of participants and the duration of follow-up. Even though our results indicate that childhood PA is a poor predictor of adolescent BMI and WC, it is possible that PA measured during early childhood can predict adiposity later in childhood [266] and that PA can predict adiposity in the short term (e.g. follow-up ≤ 2 years) [70, 166, 185]. However, it is also possible that more sensitive adiposity measures (e.g. DXA) than used in the present study are necessary to detect prospective associations between childhood PA and adolescent adiposity [70, 267]. Lastly, it is important to consider that the exposure only represents a snapshot of habitual PA, and that the number of participants included in the prospective analyses was rather moderate.

5.4 Correlates and determinants of physical activity

5.4.1 Schools' outdoor areas

Paper III suggests weak but favorable associations between the availability of permanent play facilities in the schools' outdoor areas, ST, and LPA during school hours among 6-year olds, but not among 9- or 15-year olds. Permanent play facility availability was not associated with MVPA in any of the three age groups. Associations between the availability of outdoor play space and PA during school hours were only observed among 15-year olds, but these were very weak and likely not clinically meaningful.

The lack of clear, favorable associations between the availability of permanent play facilities and objectively assessed PA is in line with the literature, which varies in its conclusions with regard to the actual importance of permanent play facility provision for children's PA during school hours [190, 191, 194, 195, 197, 198, 268]. This may reflect actual differences in the everyday life of children in different study populations, e.g. due to different school policies regarding recess periods and PA. However, in studies reporting more clear associations, they have weighted the permanent play facilities based on the number of children that could potentially use them at the same time during recess periods [194, 195, 198]. This probably gives a more detailed picture than in our study; where we weighted all individual play structures equally. Associations in our data may therefore have been underestimated or washed out if a considerable amount of the counted play facilities were never used or were only used by a few children at a time during recess.

Nevertheless, we currently know little about how different types of permanent play facilities affect the PA level of different groups of children (e.g. active vs. inactive, boys vs. girls, younger vs. older). To aid the development of PA-promoting outdoor play area designs, future studies should therefore try to address further the qualities of different facilities, not just the quantity. Although a handful of small-scale intervention studies indicate that simple, low-cost alterations to the schools' outdoor play areas may have beneficial effects on recess PA [269, 270], at least in the short to medium term [268], a great deal remains unknown.

The size of schools' outdoor play areas is regularly a topic of debate in Norway, often sparked by concerns regarding the very limited size of the outdoor play areas in some inner-city schools. A common notion is that this lack of space limits the pupils' freedom of movement and thus PA. However, few studies have actually tested this hypothesis, especially among older children and adolescents [190].

The lack of an association between the size of schools' outdoor play areas and objectively assessed PA observed in **Paper III** is in agreement with studies conducted in New Zealand and Denmark [194, 195], but contradicts studies conducted in the U.S. [271], Australia [190], England [191], Belgium [193], Spain [192], and Cyprus [196]. This may reflect that popular recess activities in some countries require more space than popular recess activities in others (e.g. basketball vs. soccer) or that the design of outdoor areas is more important than the size. It is noteworthy, however, that the available play space per pupil was considerably larger in our study and in the studies conducted in Denmark and New Zealand than in studies finding an association. In **Paper III**, only four of the 60 primary schools provided < 15 m^2 of outdoor play space per pupil, whereas in the studies conducted by Ridgers et al. (2010) and D'Haese et al. (2013) [191, 193], none of the studied schools provided > 16.9 m^2. It is therefore plausible that small outdoor play areas might inhibit the PA level of children, but that most Norwegian schools provide children with sufficient outdoor play space to be physically active. This is supported by explorative analyses of the third of schools in **Paper III** (n = 16) providing the least play space per pupil (4-40 m^2), indicating a positive association between play space and MVPA among 9-year olds (data not shown).

5.4.2 Sleep

The results from **Paper IV** did not indicate that sleep duration is a correlate or determinant of MVPA in Norwegian 9- and 15-year olds. Thus, the results do not indicate that a lack of sleep negatively affects time spent in MVPA in children or adolescents at the population level or that sleep duration during childhood affects the age related decline in MVPA from childhood to adolescence. Our cross-sectional findings are in line with most [202, 204, 206-209, 211, 272], albeit not all [203, 205] previous studies investigating associations between both self-reported and objectively assessed sleep (duration as well as efficiency) and objectively assessed PA. To our knowledge, no previous study has investigated the prospective association between sleep during childhood and objectively assessed MVPA during adolescence.

Among the 9- and 15-year-old participants, 17% and 46% reported that they slept less than what is recommended, respectively [200]. Given the negative physical and mental health outcomes associated with insufficient sleep in children and adolescents [199], this might be a cause for concern, although it should be noted that the amount of sleep children and adolescents actually need is still debated and largely unknown [273]. It is possible that efforts to optimize the sleeping habits of Norwegian children and adolescents can contribute to better public health, but current evidence yields it unlikely that MVPA represents a significant factor in the pathway between sleep and health outcomes, or vice versa. In other words, the health benefits of sufficient sleep and MVPA seem to be independent of each other [210]. However, although self- and proxy-reported measures of sleep duration in children and adolescents similar to what we used are consistently correlated with objective criterion measures [273], more research is needed to evaluate the relationship between objectively assessed sleep quality and PA.

5.4.3 Screen time

Although highly significant, the cross-sectional associations observed between screen time and MVPA in **Paper IV** were weak and do not support the notion that screen-based activities displace large amounts of MVPA. This is in line with the single other study investigating the association between screen time and accelerometer assessed PA in Norwegian 11-year olds [222]. Furthermore, the results are in line with a systematic review and meta-analysis conducted by Pearson et al. (2014) [274], showing a significant, but small, inverse association between screen time and both objectively assessed and self/proxy-reported PA in children and adolescents.

Few previous studies have investigated whether screen time during childhood is prospectively associated with MVPA during adolescence. Our results do not indicate that screen time at age nine predicts MVPA at age 15. This is in line with a study conducted by Hearts et al. (2012) [225], in which the screen time of U.S. 10-16 year olds did not predict their accelerometer assessed MVPA at age 12-18. It is also in line with a study conducted by Hands et al. (2011) [221], in which screen time during childhood did not predict self-reported PA in Australian 14-year olds.

Opportunities for screen-based leisure activities seem to be ever increasing in young people [259]. Although young people's screen behaviors are evolving rapidly, making it more challenging to weigh the potential pros and cons of total screen time, television watching continues to make up a large proportion of young people's screen time [275]. Given the medium to strong evidence of associations between television watching and several health outcomes among children and adolescents [212], a reduction in screen time may therefore still be desirable. Our results and other evidence to date however indicate that improvement in MVPA and reduction in screen time may be largely independent of each other. Hence, when developing interventions to promote MVPA, strategies targeting a reduction in screen time may only be beneficial when employed as part of a broader package of measures targeting the determinants of MVPA [274].

5.4.4 Active school transport

In **Paper IV**, the cross-sectional results indicate that both 9- and 15-year olds that walked or cycled to school accumulated more MVPA on weekdays than their peers using passive means of transportation. This corroborates the findings in 22 out of the 28 studies identified by Larouche et al. (2014) that investigated the association between active school transport and accelerometer assessed PA in children and/or adolescents [226]. Our results are also in line with a more recent systematic review and meta-analysis, finding that walking to and from school contributed an average of 17 and 13 min/d of objectively assessed MVPA in western primary and lower secondary school pupils, respectively [276]. Furthermore, our results indicate that the association between MVPA and active school transport is dose-dependent, which is in line with two previous studies [277, 278]. Active school transport thus seems to represent a good behavioral target to increase levels of MVPA in children and adolescents. However, the lack of a prospective association indicates that school transport is not enough to provide children with the skills or motivation to maintain a more active lifestyle into adolescence. Interventions aiming to increase active transport to school should therefore be aimed at both children and adolescents.

A complex and varied array of factors may influence children's and adolescents' modes of transport to school [279] and interventions promoting active school transport based on an ecologic framework with multi-level strategies seem more efficient than interventions focusing on single factors [280]. In Norway, the Institute of Transport Economics have conducted two nationwide surveys on active school transport [281]. In both 2005 and 2013/14, more than one third of parents reported that traffic made it unsafe for their child to walk or cycle to school. Conditions reported to make the school road unsafe included high traffic density and speed along the road, lack of walking/cycling paths, lack of sidewalks, lack of pedestrian crossings, bad snow clearance during winter, high traffic density and speed at crossings, and lack of lights at pedestrian crossings. This suggests that interventions at the environmental and policy related levels to increase traffic safety may be necessary to make active school transport acceptable to parents. Other components to consider include traffic safety awareness in children, which will also potentially increase parents' confidence in their child pursuing safe active school transport.

Lastly, several recent interventions have tested the efficacy of so-called walking school buses in increasing active transport to school and PA in children, demonstrating promising results. Reviewing 12 such intervention studies, Smith et al. (2015) concluded that by tackling barriers of time constraints, volunteer recruitment, and parents' safety concerns, while at the same time increasing convenience and time savings for families, future walking school bus interventions are likely to be more sustainable and taken up by more schools [282].

5.4.5 Sports or exercise participation

The cross-sectional results in **Paper IV** suggest that facilitation of sports or exercise participation might be a viable strategy to increase levels of MVPA in children and adolescents. This lends support to the advocacy of sport participation as one of seven "investments that work" in the campaign against physical inactivity put forward by the International Society for Physical Activity and Health [232]. The strength of the associations we observed are comparable to those reported by Hebert et al. (2015) in Danish children and Marques et al. (2016) in Portuguese adolescents [238, 283]. However, we did not observe an association between time spent on sports and/or exercise and MVPA in 9-year-old girls.

One possibility is that 9-year-old girls and boys accumulate different levels of MVPA during the same sports or exercise activities. There is however very little data available to support this. In one study, the proportion of time spent in MVPA (33%) did not differ between 9-year-old girls and boys during indoor soccer matches [284]. Similarly, 7-14 year old girls and boys accumulated very similar levels of MVPA during soccer practices in a study by Leek et al. (2011) [235]. However, the latter study did find significant differences in MVPA between girls and boys during baseball/softball practices. The participation rates in different sports differ between girls and boys in Norway [285]. Hence, other plausible explanations might be that the 9-year-old girls and boys participated in different sports or exercise activities that yield different levels of MVPA or that are measured with different levels of accuracy by accelerometry (e.g. aesthetic sports vs. ball sports).

A compensatory mechanism has been suggested whereby when PA is high in one domain (e.g. during sport/exercise), levels of PA in other domains are reciprocally lower [286]. This might result in similar daily levels of MVPA between girls who have differing levels of sports/exercise participation. However, current research testing this "activity-stat" hypothesis is inconclusive and does not suggest a sex difference [286].

Like for active school transport, a variety of factors needs to be considered when developing strategies to increase participation in sports and exercise. These include social support from parents and friends [287], SES [288], and costs associated with sport participation [289]. Further research is needed to understand why daily levels of MVPA seem unrelated to sports/exercise participation in preadolescent Norwegian girls and whether promotion of sports/exercise participation is thus a viable strategy to increase levels of MVPA in this group.

The results from our prospective analyses support the few previous studies investigating whether sports participation during childhood predicts adolescent MVPA [236, 240]. Thus, the evidence to date does not indicate that a general promotion of sports and/or exercise participation during childhood is sufficient to protect against the well-established MVPA decline from childhood to adolescence. The cross-sectional association between sports/exercise participation and MVPA in 15-year olds instead indicates that policy and intervention should focus on preventing dropout and encouraging uptake of sports participation in adolescents. Dropout rates from organized sport during adolescence continue to be high in Norway. Research has identified both internal and external factors affecting the decision to discontinue organized sport participation, but a lot remains unknown [290]. Hence, we should incorporate these known factors when addressing dropout, whilst simultaneously investing in identifying additional determinants.

Lastly, this is a topic of research very much in its infancy. With technological advances, objective assessment of the types of activities children undertake might become feasible in large-scale studies. At present, mismatches in the accuracy of measurements might obscure potential associations between self/proxy-reported sports/exercise participation during childhood and objectively assessed PA during adolescence [240].

5.5 Study design, selection bias, and generalizability

Papers I-IV all present results based on cross-sectional data. This type of data is ideal to assess PA levels and prevalence of adherence to PA recommendation in large populations and to study correlates of PA. However, because all data are collected at the same time point, a temporal sequence is often impossible to work out, making causal inference difficult [291, 292]. Further, because there is no random allocation to comparison groups, unmeasured or poorly measured confounding factors may affect relationships between PA and other variables.

Papers I, II and IV also present results based on a prospective cohort study following the same individuals from age nine to 15. This type of study design represents the best way to study how PA and other factors change naturally over time [293]. Further, the longitudinal nature of cohort studies enables the assessment of causal hypotheses, since it is known whether exposure (e.g. PA) occurred prior to outcome (e.g. WC) [294]. However, cohort studies have some important limitations. First, there is no random allocation to comparison groups at baseline. Study participants that differ in terms of the exposure variable of interest at baseline (e.g. PA level) are likely to differ in other important ways from each other [293]. Hence, unmeasured or poorly measured confounding factors may affect relationships between exposures and outcomes. Second, cohort studies are prone to dropout and differential losses to follow-up between those exposed (e.g. physically inactive) and those unexposed (e.g. physically active) can bias results [293, 294].

The samples of 9- and 15-year olds included in PANCS1 were invited through nationally representative samples of schools. In PANCS1, the headmasters of 63 out of the 68 schools we invited approved their school's participation. Of these schools, 89% of the invited 9-year olds and 74% of the invited 15-year olds participated in the study. These are satisfactory participation rates and higher than in many comparable studies of that period [111, 150, 241, 295-297]. The fact that only five schools declined to participate and that schools from all regions of Norway participated gives confidence in the representativeness of the PANCS1 study samples.

The samples of 6- and 9-year olds included in PANCS2 were also invited through nationally representative samples of schools. In PANCS2, the number of schools that declined participation was not revealed to the PANCS2 study group, but 6- and 9-year olds from 61 primary schools spread across all regions of Norway participated. In these schools, 56% of the invited 6-year olds and 73% of the invited 9-year olds participated in the study. The participation rate of 9-year olds is satisfactory, albeit lower than in PANCS1. The participation rate of 6-year olds is acceptable and comparable to or higher than in other studies including children of a similar age [114, 298].

We did not formally investigate reasons for not participating or participation bias in PANCS2. However, it was a common perception that the 6-year olds' parents were more skeptical of participation because of the extra workload it would involve to make sure that their child wore the accelerometer every day. Further, the proportions of the 9-year olds' mothers (45.3%) and fathers (33.2%) with a higher education were comparable to the proportions in 30-49 year old Norwegian women (46.8%) and men (34.3%) in 2011 [299]. The proportions of the 6-year olds' mothers (52.7%) and fathers (36.0%) with a higher education were however higher, indicating that the 6-year-old sample in PANCS2 may have had a somewhat higher SES than the general population.

Of the 1,759 15-year olds invited to participate in PANCS2, a total of 1,106 (63%) participated in the study. This is an acceptable participation rate and is comparable to the participation rates in other European samples of adolescents assessed with accelerometers [300]. Because 101 of those followed up from previous participation in PANCS1 had moved to another school district (contacted by mail), we do not know which lower secondary schools all of the 15-year olds in

PANCS2 went to. However, 15-year olds from at least 47 lower secondary schools spread across all regions of Norway participated.

Of the 1,119 15-year olds invited based on previous participation in PANCS1, 338 (35%) chose not to participate. This could be expected based on attrition rates reported in similar studies [146]. The loss to follow-up analysis revealed significant baseline differences between the prospective study sample and those lost to follow-up for outcome variables in **Paper I, II, and IV** (MVPA, WC, and BMI) and for predictor variables in **Paper II and IV** (MVPA, screen time, sleep, and sports/exercise). In **Paper I**, the higher baseline level of MVPA among girls could have led to and underestimation of the true longitudinal change in MVPA from age nine to 15 if MVPA tracking was strong. However, our own results do not indicate a high degree of tracking. Therefore, it is also possible that regression toward the mean can have caused an overestimation of the longitudinal MVPA decline in girls [301]. It is difficult to assess whether the different baseline levels of MVPA (**Paper II**), screen time, sleep, and sports/exercise (**Paper IV**) between the prospective study sample and those lost to follow-up affected the prospective associations with BMI and WC (**Paper II**) or MVPA (**Paper IV**). Nevertheless, generalization of the results from **Papers I, II, and IV** should be done with some degree of caution.

5.6 Strengths and limitations

5.6.1 Strengths of the studies

The use of accelerometers to assess PA objectively in large population-based samples is a major advantage of **Papers I-IV**. This eliminates biases associated with self-reported PA [37, 302], gives confidence in the generalizability of the results, and reduces the risk of type 2 errors caused by a lack of statistical power. Further, we collected all the accelerometer data using a 10-second epoch. This allows a more accurate recording of the intermittent and spontaneous PA pattern common in children [303] and is therefore a strong point of the present studies.

Another strong point of the study is the very high accelerometer wear compliance. **In paper I and II**, the mean (SD) accelerometer wear time was 731 (55) min/d in 6-year olds, 773 (64) min/d in 9-year olds, and 792 (86) in 15-year olds. In **Paper IV**, the mean (SD) accelerometer wear time on weekdays was even higher and in **Paper III**, only a fraction of the study sample had < 95% of school day minutes recorded.

The measured rather than self-reported assessment of BMI and WC in **Paper II** is another advantage [302]. Lastly, the large sample sizes allowed us to adjust the statistical models used in **Papers I-IV** for a number of covariates, to reveal interactions and to stratify analyses by sex. This reduces the risk of confounding, enables detection of modifying and moderating factors, and allows a more detailed depiction of results.

5.6.2 Limitations of the studies

Several limitations in **Studies I-IV** need addressing. First, the accelerometers assessed PA through vertical accelerations at the hip and could not be worn during water-based activities. Thus, they mainly captured ambulatory PA and underestimated the intensity of load-bearing and uphill ambulation. Second, the assessment period only provides a snapshot of the participants' PA level that may not be representative at the individual level. However, the combination of criteria of non-wear, valid day, and number of valid days chosen in **Papers I, II and IV** has been shown to give a reliable estimate of children's habitual PA at the group level [87]. Furthermore, there was no indication that the overall PA level differed between included participants with a different number of valid assessment days. Third, the potential bias introduced by using different ActiGraph models must be kept in mind when comparing the PA data in PANCS1 and PANCS2 (**Paper I**, covered in detail in Section 5.1). Fourth, there is currently no consensus on which cut-points best discriminate between ST, LPA, MPA and VPA in children and adolescents and we acknowledge that choosing other cut-points might have altered the results (**Papers I-IV**) [304]. Fifth, despite the relatively high participations rates, a considerable proportion of the samples eligible for inclusion from PANCS1 in **Papers I and II** (17%) and **Paper IV** (24%) did not have valid PA data. However, approximately 40% of the missing accelerometer data in PANCS1 was caused by monitor malfunction, which likely means that missing data is random [305]. Nevertheless, we cannot rule out the issue of selection bias. Sixth, BMI and WC are indirect, crude measures of adiposity [153, 155] and we did not control for putative confounding factors such as energy intake, sleep, and genetic factors in **Paper II**. Hence, the results should be interpreted accordingly. Lastly, the absolute validity of the questions used to assess screen time, active transport to school, and sports/exercise participation in **Paper IV** is unknown. Even if other studies have used similar methods and we consider the face validity reasonable, this is a limitation. In addition, random measurement error is inherent when self-report is used to assess the quantity of behaviors in young people. This may lead to regression dilution bias, increasing the risk of type 2 errors.

6. Conclusions

Based on the previous chapters, the following conclusions can be drawn:

- The proportions of 9- and 15-year olds adhering to the Norwegian PA recommendations were similar in 2005/06 and 2011/12. However, our data indicate that both 9- and 15-year olds in 2011/12 spent less time in LPA and more time sedentary compared to 9- and 15-year olds in 2005/06.
- Overall PA decreased and ST increased by more than 30% in both girls and boys from age nine to 15. In girls, LPA and MVPA decreased by 44% and 26%, respectively. In boys, the corresponding decreases were 39% in LPA and 28% in MVPA.
- Isotemporal substitution of ST with MPA and VPA is favorably associated with BMI and WC in children. In adolescents, favorable associations were only observed when ST was substituted with VPA. Substitution of ST with MPA and VPA at age nine was not associated with BMI or WC at age 15.
- Increasing the number of permanent play facilities in schools' outdoor play areas may be beneficial for reducing ST and increasing time spent in LPA among 6-year olds, but not among 9- and 15-year olds. In general, the size of schools' outdoor play areas does not seem to be a limiting factor for PA in Norway. This may be explained by the large outdoor areas generally observed in Norwegian schools.
- In agreement with a growing body of evidence, we found positive associations between active school transport, sport/exercise participation, and habitual MVPA on weekdays. Moderate-to-vigorous PA on weekdays does not however seem associated with sleep duration and only weekly associated with screen time.
- Sleep duration, screen time, active school transport, and sports/exercise participation at age nine does not seem associated with MVPA at age 15.

7. Implications, recommendations, and future research

Paper I:

- Because of the ample evidence of the beneficial health effects of PA and the lack of improvement in the PA levels of children and adolescents since the mid-2000s, efforts to increase children's and adolescents' PA levels should be given higher priority in coming years.
- Efforts made to avoid the large decline in PA when going from childhood to adolescence should start at an early age and encompass all children, not only those with the lowest levels of PA.
- In order to evaluate public health actions to increase PA at the population level that have been initiated since PANCS2, it is essential that future studies utilize similarly comprehensive sampling and comparable techniques of PA assessment.
- Large randomized controlled trials in children and adolescents with objectively assessed PA as the primary outcome are few and far between. In order to evaluate causal mechanisms between PA, its correlates, and determinants identified through observational research, experimental studies are a priority.
- To improve our understanding of the timing and magnitude of changes in PA, we need more longitudinal studies spanning both childhood and adolescence and using multiple assessment points.

Paper II:

- Whether meaningful reductions in the prevalence of overweight and obesity are achievable in children and adolescents from a 10 min/d reallocation of time spent sedentary to PA of moderate and/or vigorous intensity needs to be confirmed in randomized controlled trials.

Paper III:

- The sheer number of permanent play facilities or the size of schools' outdoor play areas do not seem to be strong environmental correlates of PA in Norway. However, this does not indicate that the design of schools' outdoor play area is unimportant for the promotion of PA during school hours.
- In order to develop cost-effective outdoor play area designs that promote PA, future research needs to investigate what types of permanent play facilities have the largest PA-promoting potential, especially among adolescents.

- Future research should also emphasize schools with small outdoor play areas and try to identify strategies that provide the best opportunities for PA in these schools.

Paper IV:

- Public health interventions aiming to increase PA in children and adolescents should increase opportunities for active school transport and participation in sports and exercise activities.
- Methodological advances are needed to provide researchers with more accurate data on PA levels during non-ambulatory active transport and different sport and exercise activities.
- Because young people's screen behaviors have change markedly in recent years and continue to evolve rapidly, new, objective assessment methods for screen behavior are warranted to increase our understanding of the relationship between screen behaviors and physical activity.

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Errata

Paper IV

Since submission to the doctoral committee, Paper IV has been accepted for publication in BMC public health (24.05.2018). Corrections have been made in each chapter of the paper.

Paper I

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ORIGINAL ARTICLE

WILEY

Secular and longitudinal physical activity changes in population-based samples of children and adolescents

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The aims of this study were to investigate whether physical activity (PA) and sedentary time (ST) in 9- and 15-year-olds differed between 2005-2006 and 2011-2012 (secular change), and to investigate changes in PA and ST from age 9 to 15 (longitudinal change). In 2005-2006, we invited nationally representative samples of Norwegian 9- (n=1470) and 15-year-olds (n=1348) to participate. In 2011-2012, we invited a new nationally representative sample of 9-year-olds (n=1945), whereas 15-year-olds (n=1759) were invited to participate either based on previous participation in 2005-2006 or from a random sample of schools. We assessed PA and ST objectively using accelerometers. In 2011-2012, both 9- and 15-year-olds spent more time sedentary (≥35.7 min/d, *P*<.001) and less time in light PA (≥35.2 min/d, *P*<.001) compared to their peers in 2005-2006. Nine-year-old girls also spent less time in moderate-to-vigorous PA (MVPA) (4.2 min/d, *P*=.041). In both age groups, the proportion accumulating an average of 60 min/d of MVPA did not differ between the two cohorts. From age 9 to 15, girls and boys decreased their time spent in LPA (≥106.7 min/d, *P*<.001) and in MVPA (≥20.8 min/d, *P*<.001). During the same period, ST increased by a mean of >2 h/d (*P*<.011). We observed an adverse secular change in PA from 2005-2006 to 2011-2012 among 9- and 15-year-olds, and a large decline in PA in the participants followed longitudinally from age 9 to 15 years.

KEYWORDS
accelerometer, MVPA, prospective, sedentary

1 | INTRODUCTION

Children and adolescents spend a large proportion of their awake time sedentary, and many do not reach the recommended level of MVPA.[1] Therefore, increasing young peoples' PA is a global priority,[2] and regular national surveillance of PA and ST is warranted to evaluate changes and trends.

Change in PA levels over time (secular changes/trends) has previously been investigated in large population-based studies of adolescents, and results have indicated that PA levels remained relatively stable from the 1980s to the 2000s in Europe[3] and the USA.[4] However, in a recent review it was suggested that the proportion of adolescents (age 11-17) not achieving ≥60 min/d of MVPA had increased in 32 of the 50 countries investigated.[1] Most previous studies have relied on self-reported measures of PA, however, which are especially prone to recall bias,[5] and only provide crude estimates of the amount and intensity of PA.

In recent years, accelerometers have increased our ability to monitor the volume, pattern, frequency, intensity, and duration of habitual PA objectively in large-scale studies.[6] Although they are not without some limitations,[7] the objective nature of accelerometers removes the potential for recall bias and, to a large extent, social-desirability bias.[8] However, only a handful of studies have used accelerometers to investigate secular changes in the PA level of children[9,10] and

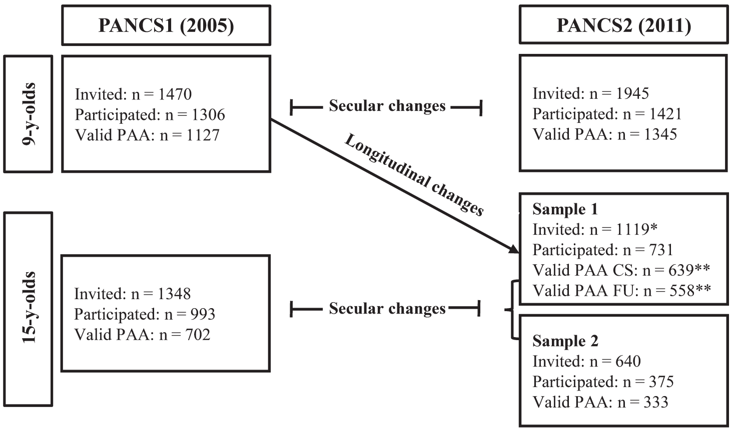

FIGURE 1 Flowchart of the study populations in PANCS1 (2005) and PANCS2 (2011). PAA=physical activity assessment. CS=cross-sectional sample. FU=follow-up sample. *1119 of the 1306 9-y-olds that participated in PANCS1 were found and invited to participate in PANCS2 as 15-y-olds. **81 of the participants that participated in both 2005 (age 9) and 2011 (age 15) only provided valid PA data in 2011 and were not included in the longitudinal analyses (639-81=558)

adolescents[11] so far, of which only one was conducted in a nationally representative sample.[11] In addition, no published studies have investigated secular changes in accelerometer assessed PA from the mid-2000s onward.

Furthermore, there are only a limited number of studies that have studied changes in accelerometer assessed PA from childhood to adolescence within the same individuals (longitudinal trends).[12-16] Although these studies vary in terms of baseline age (5-12 years), age at last follow-up assessment (14-18 years), and time between baseline and last follow-up assessment (4-12 years), a decline in overall PA and/or time spent in MVPA from childhood to adolescence was reported in all but one study (from age 12-16).[14] However, none of these previous studies were conducted in nationally representative samples, which may limit the generalizability of the results.

In the Norwegian PA among Norwegian Children Study (PANCS), accelerometer data in large cohorts of 9- and 15-year-olds collected in 2005-2006 (PANCS1) and in 2011-2012 (PANCS2) are available. Due to the design of PANCS, it is possible to investigate both secular and longitudinal PA changes. Consequently, the aim of this study was twofold: (a) to investigate whether the physical activity (PA) level and sedentary time (ST) of 9- and 15-year-olds in 2011-2012 differed from that of 9- and 15-year-olds in 2005-2006 (secular changes) and: (b) to investigate changes in PA and ST from age 9 to 15 (longitudinal changes).

2 | METHODS

2.1 | Participants

In PANCS1, we selected nationally representative, cross-sectional samples of 9- and 15-year-olds using cluster sampling with schools as the primary unit. When a school agreed to participate, we invited all pupils in grades 4 and 10 to enroll. The PANCS2 study had a mixed design. We selected a new nationally representative, cross-sectional sample of 9-year-olds using the same cluster sampling procedure as in PANCS1. The 15-year-olds, on the other hand, were invited to participate either individually based on previous participation in PANCS1 (sample 1) or selected from a random sample of the lower secondary schools that had previously participated in PANCS1 (sample 2). Figure 1 displays a flowchart of the number of 9- and 15-year-olds that were invited, participated, and provided valid PA assessments in the two studies.

The Regional Committee for Medical Research Ethics approved PANCS1, and the Norwegian Social Science Data Services approved both studies. We obtained written informed consent from all participants and their primary guardians before the start of both rounds of data collection.

2.2 | Anthropometrics

We measured weight and height to the nearest 0.1 kg (Seca 770 and 877, SECA GmbH, Hamburg, Germany) and 0.1 cm (wall-mounted measuring tape), respectively. In PANCS1, participants wore underwear during the anthropometric measurements whereas in PANCS2, participants wore light clothing (gym shorts/pants and T-shirt). Thus, we subtracted 0.3 kg from the bodyweight measures in PANCS2 to account for clothing. We calculated body mass index (BMI) using weight and height ($kg \cdot m^{-2}$).

2.3 | Physical activity

We assessed PA using ActiGraph accelerometers (ActiGraph, LLC, Pensacola, Florida, USA), which participants wore on their right hip. In PANCS1, we used the CSA 7164 model and instructed the participants to wear the monitor for all waking hours (except during showering and bathing) for four consecutive days, including two weekend days. In PANCS2, we used the GT1M and GT3X+ models and instructed the participants to wear the monitor during all waking hours (except during showering and bathing) for seven consecutive days. We initialized the monitors to start recording at 06:00 on the day after the participants received them. We used the ActiLife software (ActiGraph, LLC, Pensacola, Florida, USA) to initialize the monitors and to download the accelerometer files. For further processing (vertical accelerations only), we used KineSoft (v3.3.76; KineSoft, Rothesay, New Brunswick, Canada). Due to the sporadic nature of children's PA,[17] an epoch period of 10 sec was used. After excluding data recorded from 00:00 to 06:00 and all intervals of ≥20 consecutive minutes with no accelerations recorded, we considered days with ≥480 minutes of activity recordings valid. For our main analyses, we included all participants with ≥2 days of valid activity recordings. This combination of non-wear, valid day, and number of valid days-criteria has been shown to give a reliable estimate of children's habitual PA.[18]

As a measure of overall PA, we used average counts·min^{-1} (CPM) over the whole assessment period. To investigate average minutes per day (min/d) spent sedentary, in LPA and in MVPA, we divided time registered with <100 CPM, 100-1999 CPM and ≥2000 CPM by valid assessment days, respectively. The <100 CPM cut-point is widely applied and has been shown to provide a realistic estimate of the time children spend doing sedentary activities and to exhibit excellent classification accuracy compared with indirect calorimetry.[19,20] The MVPA cut-point of 2000 CPM was developed for the European Youth Heart Study (EYHS) and is equivalent to a walking speed in children and adolescents of >4 km/h.[21] Time registered above the sedentary cut-point, but below the MVPA cut-point, was categorized as LPA (100-1999 CPM). Participants were categorized as compliant with the Norwegian PA recommendations if they accumulated an average of ≥60 min/d of MVPA. In PANCS1, we collected accelerometer data during all months of the year except in July and August. In PANCS2, we collected accelerometer data from March to December, with the exception of July.

2.4 | Socioeconomic status

We used parental education level as a proxy for socioeconomic status (SES). In PANCS1, the parents self-reported this information, whereas in PANCS2, Statistics Norway provided the information (register data). Based on the parent with the highest education level, we categorized the participants into three SES groups: low (primary school or lower secondary school), middle (high school [vocational or general studies]), and high (University College or University).

2.5 | Sample size calculations

In PANCS2, we based our sample size calculations on the ability to detect subgroup differences in overall PA (CPM) of 7%, either within the same cross-sectional sample (eg, between boys and girls) or between cross-sectional samples in different studies (secular changes). Using the variability known from PANCS1 (SD=280 CPM), calculations revealed that we would need 516 individuals in each age and sex group to detect subgroup differences in CPM of 7% (49 CPM) using a two-tailed test (1-β=0.90; two-tailed α=0.05). Because of cluster sampling, we incorporated a design effect of 1.1, yielding a final target sample size of 567 individuals in each age and sex group. For our longitudinal sample, we invited all those who participated in PANCS1 at age 9 (n=1306) to participate in PANCS2 at age 15 (Figure 1).

2.6 | Analysis

To account for cluster sampling, we included school as a cluster variable in all statistical models to obtain robust standard errors. In analyses of the longitudinal sample, we used school at baseline (age 9 years) as the cluster variable. We performed all statistical analysis using Stata SE 13.1 (StataCorp. 2013. Stata Statistical Software: Release 13. College Station, TX: StataCorp LP.).

2.6.1 | Secular changes

To analyze secular changes in PA, we used generalized linear models (continuous outcomes) and logistic regression (categorical outcomes) with study year as a binary predictor variable. In the crude models, we only adjusted for accelerometer wear time (except for analyses with CPM as the outcome). In the adjusted models, we adjusted for wear time (except for analyses with CPM as the outcome), age, season (1: March-May, 2: June-August, 3: September-November, 4: December-February), and SES. In analyses of 15-year-olds, we also adjusted for whether or not the participants in PANCS2 had previously participated in PANCS1 at age nine (0/1). To investigate whether the secular changes differed between girls and boys, we included the two-way interaction term *study year*sex* in the models. Results indicated sex by study year interactions in analyses of three of the five outcome variables among 15-year-olds ($P \leq .050$), but not among 9-year-olds. Because of the high number of participants, and thus low risk of losing statistical power, we

TABLE 1 Descriptive characteristics of the cross-sectional samples of 9- and 15-y-olds providing valid PA data in 2005 and 2011 (mean ± SD unless otherwise specified)

	9-y-olds				15-y-olds			
	Girls		Boys		Girls		Boys	
	2005	2011	2005	2011	2005	2011	2005	2011
n	526	693	601	652	361	489[a]	341	483[b]
Age (y)	9.6 ± 0.4	9.6 ± 0.4	9.6 ± 0.4	9.6 ± 0.4	15.6 ± 0.4	15.2 ± 0.6*	15.6 ± 0.4	15.2 ± 0.6*
Height (cm)	138.4 ± 6.8	138.0 ± 6.5	139.9 ± 6.2	138.7 ± 6.8*	165.6 ± 6.5	165.0 ± 6.2	175.6 ± 7.1	173.2 ± 8.0*
Weight (kg)	34.0 ± 7.1	33.7 ± 6.8	33.9 ± 6.3	34.0 ± 7.0	58.0 ± 8.2	57.4 ± 9.5	65.2 ± 12.8	62.3 ± 12.0*
BMI (kg·m^{-2})	17.6 ± 2.7	17.6 ± 2.7	17.2 ± 2.4	17.6 ± 2.8*	21.1 ± 2.8	21.1 ± 3.1	21.1 ± 3.7	20.7 ± 3.3
SES (%)								
Low	5	8	9	6	2	6	5	8*
Middle	41	36	35	40	40	39	35	40*
High	54	56	56	54	58	54	60	53*

[a]272 participated in PANCS1 as 9-y-olds.
[b]286 participated in PANCS1 as 9-y-olds.
*Significantly different from the study sample in 2005 (all *P*-values≤.047).
BMI, body mass index; SES, socioeconomic status.

chose to stratify analyses of both age groups by sex. Within-study sex differences in PA and between-study differences in age, anthropometrics, and SES were analyzed using generalized linear models, logistic regression, and ordered logistic regression, respectively.

2.6.2 | Longitudinal changes

We analyzed longitudinal changes using random-effects linear models (continuous outcomes) and conditional fixed effects logistic regression (categorical outcomes) with age as a binary predictor variable. With the exception of analyses with CPM as the outcome variable, we adjusted both crude and adjusted models for accelerometer wear time. In the adjusted models, we also adjusted for SES, season at both assessment points, and number of days between PA assessments. To investigate whether changes from age 9 to 15 years were different in boys and girls, we included the two-way interaction term *sex*age* in the models. Because these analyses indicated sex by age interactions for three of the five outcome variables (*P*≤.027), we stratified all analyses by sex. We analyzed sex differences in PA at baseline and follow-up using random-effects linear models and random-effects logit models. The same models were used to study baseline differences in anthropometrics and PA between the included study sample and those lost to follow-up. Baseline differences in SES between those included in the study sample and those lost to follow-up were analyzed using random-effects ordered logistic models. To assess tracking of the continuous PA variables from age 9 to 15 years, we categorized the participants into variable-specific quintiles and calculated Spearman's rank correlation coefficients. To assess whether the odds of meeting the Norwegian PA recommendations at age 15 was different between those that met and did not meet the recommendations at age 9, we used random-effects logit models.

3 | RESULTS

3.1 | Secular changes

In total, 2472 (90.6%) of the participating 9-year-olds and 1674 (79.8%) of the participating 15-year-olds provided valid PA assessments and were included in the analyses of secular changes. Table 1 displays descriptive characteristics of the study sample by age, sex, and study year. In 2011-2012, 9-year-old boys were shorter and had a somewhat higher BMI compared to their peers in 2005-2006 (*P*≤.047). We found no significant differences in anthropometrics or background characteristics between 9-year-old girls in 2005-2006 and 2011-2012. The 15-year-old girls and boys in the 2011-2012 cohort were younger than their peers in 2005-2006 cohort were (*P*<.001). In addition, 15-year-old boys in the 2011-2012 cohort were shorter, lighter and were more likely to be categorized in a lower SES group (*P*≤.036). Table 2 displays the crude and adjusted mean (SE) PA data and results from analyses of secular changes by age, sex, and year.

3.1.1 | 9-year-olds

Overall PA in 9-year-old girls and boys was significantly lower in 2011-2012 compared to 2005-2006 (*P*≤.002). The

TABLE 2 Mean (SE) physical activity level among the 9- and 15-y-old participants in 2005 and 2011 and secular changes (mean diff (95% CI))

	Crude model[a]				Adjusted model[b]			
	2005[a]	2011[a]	Mean diff (95% CI)[a]	P	2005[b]	2011[b]	Mean diff (95% CI)[b]	P
9-y-old girls								
n	526	693			479	676		
Overall PA (CPM)	682 (24.6)	585 (15.1)	−96.3 (−152.9, −39.7)	<.001	677 (20.6)	589 (11.3)	−87.8 (−134.6, −41.0)	<.001
Sedentary (min/d)	429 (3.1)	471 (2.8)	42.5 (34.2, 50.7)	<.001	430 (3.3)	470 (2.2)	40.4 (32.2, 48.5)	<.001
LPA (min/d)	265 (2.2)	228 (1.7)	−37.1 (−42.6, −31.7)	<.001	264 (2.2)	229 (1.6)	−35.6 (−41.2, −29.9)	<.001
MVPA (min/d)	75 (1.9)	71 (1.3)	−4.5 (−9.0, 0.0)	.051	75 (1.6)	71 (1.1)	−4.2 (−8.2, −0.2)	.041
9-y-old boys								
n	601	652			532	641		
Overall PA (CPM)	785 (20.6)*	697 (19.1)*	−87.8 (−142.9, −32.6)	.002	778 (17.1)	708 (13.3)	−69.6 (−113.5, −25.7)	.002
Sedentary (min/d)	411 (3.8)*	453 (3.4)*	42.5 (32.7, 52.4)	<.001	413 (3.4)	451 (3.0)	38.3 (28.8, 47.8)	<.001
LPA (min/d)	269 (2.5)	231 (1.7)	−37.9 (−43.8, −32.0)	<.001	267 (2.5)	232 (1.8)	−35.2 (−41.9, −28.5)	<.001
MVPA (min/d)	94 (2.3)*	90 (2.0)*	−4.2 (−10.1, 1.8)	.170	94 (2.1)	91 (1.6)	−2.9 (−8.3, 2.4)	.284
15-y-old girls[c]								
n	361	489			291	476		
Overall PA (CPM)	470 (17.3)	418 (10.2)	−52.9 (−88.5, −17.2)	.004	468 (10.3)	421 (8.4)	−47.1 (−71.7, −22.6)	<.001
Sedentary (min/d)	541 (3.8)	584 (2.2)	42.4 (33.7, 51.0)	<.001	538 (3.5)	587 (2.3)	48.9 (39.3, 58.6)	<.001
LPA (min/d)	192 (2.7)	152 (1.8)	−39.5 (−45.4, −33.6)	<.001	197 (3.1)	150 (1.7)	−47.1 (−55.6, −38.7)	<.001
MVPA (min/d)	61 (2.7)	58 (1.8)	−2.7 (−8.3, 2.9)	.350	61 (1.6)	59 (1.5)	−1.5 (−5.9, 2.8)	.487
15-y-old boys[c]								
n	341	483			255	463		
Overall PA (CPM)	527 (17.0)*	487 (12.9)*	−40.5 (−82.3, 1.83)	.061	522 (19.9)	490 (14.0)	−31.9 (−90.3, 26.4)	.284
Sedentary (min/d)	533 (4.9)*	564 (4.0)*	30.7 (18.1, 43.3)	<.001	531 (5.4)	566 (3.7)	35.7 (19.8, 51.6)[#]	<.001
LPA (min/d)	197 (3.7)	167 (2.8)*	−30.8 (−39.6, −22.0)	<.001	203 (3.5)	164 (2.2)	−38.6 (−48.3, −28.9)[#]	<.001
MVPA (min/d)	67 (2.5)*	67 (2.0)*	0.4 (−5.8, 6.6)	.902	65 (2.7)	68 (2.0)	3.4 (−4.5, 11.3)	.394

[a]Adjusted for cluster sampling (robust standard errors (SE)) and accelerometer wear time (except in analyses of CPM).
[b]Adjusted for cluster sampling, accelerometer wear time (except in analyses of CPM), age, season, SES.
[c]Adjusted for follow-up status (participation in both 2005 (at age 9) and 2011 (at age 15)) (adjusted model only).
*Significantly different from girls within same study year ($P \leq .030$).
[#]Change different between girls and boys ($P \leq .050$).
PA, physical activity; LPA, light physical activity; MVPA, moderate-to-vigorous physical activity.

TABLE 3 Description of girls (n=272) and boys (n=286) with valid physical activity assessments in both 2005 (age 9 y) and 2011 (age 15 y)

	Girls		Boys	
	2005	2011	2005	2011
Age (yrs.)	9.6 ± 0.4	15.2 ± 0.7	9.7 ± 0.4	15.2 ± 0.7
Height (cm)	138 ± 7	165 ± 6	140 ± 6	174 ± 8
Weight (kg)	33 ± 7	58 ± 9	34 ± 6	62 ± 11
BMI ($kg·m^{-2}$)	17.3 ± 2.6	21.1 ± 3.1	17.0 ± 2.1	20.4 ± 2.9
SES (%)				
Low	5	5	8	6
Middle	39	36	39	36
High	56	58	53	57

BMI, body mass index; SES, socioeconomic status.

observed mean differences of 87.8 CPM and 69.6 CPM translate to differences of 13.0% (95% CI: −19.9, −6.1) and 9.0% (95% CI: −14.6, −3.3), respectively.

In 2011-2012, 9-year-old girls spent on average 40.4 (95% CI: 32.2, 48.5) more min/d sedentary and 35.6 (95% CI: −41.2, −29.9) less min/d in LPA than 9-year-old girls in 2005-2006 (*P*<.001). We found similar differences between 9-year-old boys in the two cohorts, with corresponding differences of 38.3 (95% CI: 28.8, 47.8) min/d more and 35.2 (95% CI: −41.9, −28.5) min/d less for sedentary and LPA, respectively (*P*<.001).

We also found a significant difference in time spent in MVPA among 9-year-old girls (*P*=.041), but not boys (*P*=.284). Nine-year-old girls in the 2011-2012 cohort spent on average 4.2 (95% CI: −8.2, −0.2) min/d less in MVPA compared to their peers in 2005-2006.

In 2005-2006, 74% and 90% of 9-year-old girls and boys, respectively, met the Norwegian PA recommendations of 60 minutes of daily MVPA. In 2011-2012, the corresponding numbers were 69% and 86% (*P*≥.071).

3.1.2 | 15-year-olds

Fifteen-year-old girls in the 2011-2012 cohort had a lower overall PA level compared to 15-year-old girls in the 2005-2006 cohort (*P*<.001) (Table 2). The observed mean difference translates to 10.1% (95% CI: −15.3, −4.8). The overall PA level among 15-year-old boys did not differ significantly between the participants in the two cohorts (*P*=.284).

Both 15-year-old girls and boys in the 2011-2012 cohort spent more time sedentary and less time in LPA compared to their peers in the 2005-2006 cohort (*P*<.001). In 2011-2012, 15-year-old girls spent 48.9 (95% CI: 39.3, 58.6) more min/d sedentary and 47.1 (95% CI: -55.6, -38.7) less min/d in LPA than in 2005-2006. Fifteen-year-old boys in the 2011-2012 cohort spent 35.7 (95% CI: 19.8, 51.6) more min/d sedentary and 38.6 (95% CI: −48.3, −28.9) less min/d in LPA compared to their peers in the 2005-2006 cohort. Time spent in MVPA did not differ significantly between 15-year-olds in 2005-2006 and 2011-2012 (*P*≥.394).

In 2005-2006, the proportion of 15-year-old girls and boys meeting the Norwegian PA recommendation was 49% and 52%, respectively. Corresponding figures in 2011-2012 were 42% and 57% in girls and boys, respectively (*P*≥.072).

3.2 | Longitudinal changes

Of the 1306 girls and boys that participated in PANCS1 at age 9 years, we tracked and invited 1119 to participate in PANCS2 at age 15 years. Of these, 731 agreed to participate and 558 provided valid PA assessments at both time points. Table 3 displays descriptive characteristics of the sample. At baseline, participants included in the longitudinal study sample were similar to those lost to follow-up in terms of most variables of interest. However, girls and boys who provided valid PA data at both time points had a lower BMI at baseline compared to those lost to follow-up (*P*≤.026) (mean differences 0.5 $kg·m^{-2}$ (95% CI: −0.1, −0.9) and 0.4 $kg·m^{-2}$ (95% CI: −0.1, −0.8), respectively). Girls in the study sample also spent an average of 4.1 min/d (95% CI: 8.4, 0.2) more in MVPA at baseline than girls that were lost to follow-up (*P*=.033). There were no significant differences in any of the other PA variables (*P*≥.06).

Table 4 displays results from the longitudinal analyses. Overall PA, time spent in LPA and MVPA, and the odds of meeting the Norwegian PA recommendations was significantly reduced in both girls and boys between age 9 and 15 years (*P*<.001). In contrast, time spent sedentary increased by >2 h/day in both girls and boys (*P*<.001).

The adjusted analyses revealed that time spent in MVPA decreased from an average of 79 min/d at age 9 years to 59 min/d at age 15 years among girls and from an average of 98 min/d to 70 min/d among boys. At age 9 years, 76% and 92% of the participating girls and boys met the Norwegian PA recommendations, respectively. At age 15, the corresponding

TABLE 4 Mean (SE) physical activity level among girls (n=272) and boys (n=286) providing valid PA data in both 2005 (age 9 y) and 2011 (age 15 y), longitudinal changes (mean change (95% CI)) and tracking (Rho)

	Crude model[a]				Adjusted model[b]				Tracking[c]	
	Age 9	Age 15	Mean change (95% CI)	*P*	Age 9	Age 15	Mean change (95% CI)	*P*	Rho[c]	*P*
Girls										
Overall PA (CPM)	691 (27.2)	431 (12.3)	−259.7 (−301.0, −218.4)	<.001	713 (24.1)	414 (10.7)	−298.5 (−346.1, −250.8)	<.001	0.353	<.001
Sedentary (min/d)	433 (4.0)	573 (3.2)	139.8 (133.2, 146.4)	<.001	432 (4.0)	574 (2.8)	142.2 (134.5, 149.8)	<.001	0.201	<.001
LPA (min/d)	270 (2.8)	150 (3.0)	−119.9 (−125.6, −114.2)	<.001	269 (2.9)	150 (2.5)	−119.2 (−125.7, −112.6)	<.001	0.307	<.001
MVPA (min/d)	78 (2.3)	60 (2.3)	−18.0 (−21.5, −14.4)	<.001	79 (1.9)	59 (1.9)	−20.8 (−24.9, −16.6)	<.001	0.293	<.001
Boys										
Overall PA (CPM)	775 (22.6)*	511 (12.3)*	−263.9 (−312.2, −215.5)	<.001	791 (23.6)	503 (14.6)	−287.8 (−349.7, −225.9)	<.001	0.209	<.001
Sedentary (min/d)	419 (4.2)*	554 (3.8)*	134.8 (123.6, 146.1)	<.001	417 (4.8)	554 (3.8)	136.6 (123.4, 149.7)	<.001	0.150	.011
LPA (min/d)	274 (3.2)	166 (3.0)*	−107.5 (−115.8, −99.3)[#]	<.001	273 (3.7)	166 (2.5)	−106.7 (−116.4, −97.1)[#]	<.001	0.283	<.001
MVPA (min/d)	96 (2.7)*	70 (1.9)*	−25.8 (−31.0, −20.5)[#]	<.001	98 (2.8)	70 (1.9)	−27.8 (−34.3, −21.2)[#]	<.001	0.249	<.001

[a]Adjusted for cluster sampling (robust standard errors) and accelerometer wear time (except CPM).
[b]Adjusted for cluster sampling, SES, season, accelerometer wear time (except in analyses of CPM) and days between accelerometer measurements.
[c]Spearman's rank correlation coefficient (rho) between the different variables at age 9 and 15 (variable-specific quintiles).
*Significantly different from girls within age group ($P \leq .001$).
[#]Change significantly different from girls ($P \leq .027$).
PA, physical activity; CPM, counts per minute; LPA, light physical activity; MVPA, moderate-to-vigorous physical activity.

prevalence values were reduced to 48% in girls and 62% in boys ($P<.001$).

Girls and boys spent 54.9% (95% CI: 53.9, 55.9) and 52.7% (95% CI: 51.5, 53.9) of their waking hours sedentary at age 9 years. By age 15 years, this increased to 73.3% (95% CI: 72.6, 74.0) and 70.1% (95% CI: 69.1, 71.0) of awake time among girls and boys, respectively.

Spearman's correlation coefficients between measures of PA at age 9 and 15 ranged from 0.15 (sedentary time in boys) to 0.35 (overall PA in girls) (Table 4). All correlation coefficients were significantly greater than zero ($P\leq.012$). The odds of meeting the recommended levels of daily MVPA at age 15 years was 3.4 and 3.8 times higher among girls (95% CI: 2.0, 5.8) and boys (95% CI: 2.4, 6.0) whom met this recommended level at age 9 years, respectively, compared with girls and boys who did not ($P<.001$). At age 15 years, 56% of the girls and 65% of the boys whom met the Norwegian PA recommendations at age 9 years also did so at age 15 years.

4 | DISCUSSION

Our results indicate that the PA levels of Norwegian 9-year-old girls and boys and 15-year-old girls were lower in 2011-2012 compared to 2005-2006. Further, the results indicate that the lower overall PA level in large part results from a replacement of time spent in LPA with time spent sedentary. However, the proportion of 9- and 15-year-olds meeting the Norwegian PA recommendations did not differ significantly between the two assessment points.

Our findings corroborate previous observations using accelerometers to investigate longitudinal changes in PA, suggesting a large decline in overall PA and in PA of different intensities during the transition from childhood to adolescence, with a large corresponding increase in time spent sedentary.

4.1 | Secular trends

One of few previous studies that have investigated secular changes in objectively assessed PA in children was conducted in representative samples of 9-year-olds living in Oslo, Norway.[9] These results indicated a slightly higher overall PA level in 2005-2006 compared with results obtained 6 years earlier in 1999-2000. Further, a higher proportion of boys met the Norwegian PA recommendations in 2005-2006 than in 1999-2000. Similarly, the overall PA level and time spent in MVPA among 6- to 11-year-olds from the USA was slightly higher in 2005-2006 compared to 2003-2004,[11] and MVPA increased slightly between 1997-1998 and 2003-2004 among 8- to 10-year-old Danish children.[10] Our results may indicate a reversal or halting of the previously observed secular increase in PA.

Secular changes in PA are likely due to several different factors. Kolle et al.[9] speculated that the increase in PA they observed between 1999-2000 and 2005-2006 in 9-year-olds could be attributed to three factors: first, the launch of a national PA promoting action plan in 2004; second, implementation of school-based interventions aimed at increasing PA participation; and third, an increased media focus on the positive health benefits associated with regular PA. Although these factors may contribute to an increase in PA over a short period, our results indicate a decline in PA and a subsequent increase in sedentary time in contemporary children.

Recent results from the CANPLAY study,[22] where secular PA trends in nationally representative samples of Canadian children (ages 5-10 and 11-14) and adolescents (ages 15-19) were assessed using pedometers, show a similar pattern. Their analyses revealed an increase in steps/day between 2005 and 2008, which they in part attributed to PA strategies launched in the early 2000s, national PA guidelines launched in 2002, and a successful mass media campaign launched in 2007.[22] However, steps/day thereafter decreased, being significantly lower in 2014 compared to 2005 in all age groups.[22] Cameron et al.[22] speculate that the implementation of new and more liberal PA guidelines in Canada in 2011 may have exacerbated the decreasing trends observed in the CANPLAY study.

Moller et al.[10] hypothesized that the slight increase in MVPA observed between 1997-1998 and 2003-2004 among 8- to 10-year-old Danish children may be explained by increased participation in sport clubs.[10] In Norway, the number of sports club memberships among children and adolescents has increased substantially since the 1960s.[23] However, after 2006 it appears that the number of sports club memberships has stabilized or even decreased slightly.[23] Although we do acknowledge that participation in organized sports may not necessarily lead to higher levels of PA compared with participation in self-organized PA in children,[24] this might have contributed to the secular decline in PA.

Over the last decade, Norwegian schools have become fewer with a subsequent increase in size,[25] and the average distance travelled to/from school increased from 3.4 km in 2005 to 4.2 km in 2013-2014.[26] Pont et al.[27] systematically reviewed studies investigating environmental correlates of children's active travel and concluded that there is convincing evidence for an inverse association between travel distance and active travel. Active school transport has also been shown to be positively associated with overall PA, minutes of PA at all intensities, steps/day, and energy expenditure.[28] Thus, it can be speculated that a reduction in active school travel may have contributed to the secular decline in PA we observed among 9-year-olds.

Opportunities for sedentary leisure activities seem to be ever increasing in young people, and recent data from the Health Behaviour in School-aged Children Study revealed that in all the 30 participating countries (including Norway), computer use and total screen time increased significantly among 11-, 13-, and 15-year-olds from 2002 to 2010.[29] It is therefore possible that this has contributed to the observed secular increase in ST and decrease in LPA.

Several other factors may have contributed to secular changes in PA and ST between 2005-2006 and 2011-2012. For example, time use surveys conducted by Vaage[30] indicate that Norwegian children (age 9-12) and adolescents (age 13-15) spent more time on education, less time with friends, had less time for leisure activities, and spent less time doing sports or scouting activities in 2010 compared to 2000.

4.2 | Longitudinal changes

A direct comparison of longitudinal changes in accelerometry assessed ST and PA is challenging due to different data cleaning, reduction and processing procedures across studies. However, it appears that the relative decline (%) in overall PA observed in our study is slightly greater than observed in Danish children (Odense),[31] but slightly smaller than observed in American (Iowa) and English young people (Norfolk).[12,13] Further, it appears that the relative increase in time spent sedentary is smaller than in American (10 cities)[32] and Swedish children (Stockholm).[16] The most commonly reported construct of PA in previous longitudinal studies is time spent in MVPA. The decline in MVPA observed in the present study translates to a mean annual decline in MVPA of 3.8% among girls and 4.5% among boys. This is nearly three times less than among American children,[32] nearly two times less than in children from Stockholm (Sweden)[16] and Iowa (USA),[13] but comparable to children from Norfolk in England.[12]

When we compare the mean cross-sectional differences in overall PA observed between 9- and 15-year-olds in the two PANCS studies with the longitudinal change observed from age 9 to 15 years, the mean cross-sectional differences are in general smaller than the longitudinal change. The mean cross-sectional difference in overall PA between 9- and 15-year-old girls was 209 CPM in 2005-2006 and 168 CPM in 2011-2012, whereas the mean longitudinal change observed from age 9 to 15 was 299 CPM. We observed a similar pattern in boys (256 CPM and 218 CPM vs. 288 CPM). This exemplifies how time trends may bias cross-sectional comparisons of PA between different age groups, and why longitudinal data are necessary to obtain accurate estimates of changes in PA with age.

Although tracking coefficients for all constructs of PA were significantly greater than zero, and the odds of accumulating ≥60 min/d of MVPA at age 15 years was >3 times higher in those accumulating ≥60 min/d of MVPA at age 9 years, tracking can be considered low in the present study.[33] This may indicate that measures to prevent the observed decline in physical activity from childhood to adolescence should encompass the entire range of children, not only those with an already low PA level.

4.3 | Strengths and limitations

A major strength of this study is the large population-based samples of both children and adolescents. However, because 1696 of the 6522 invited 9- and 15-year-olds chose not to participate in PANCS (26%), we cannot completely rule out the issue of selection bias. It should be noted that we do not know how many of the non-responding children and adolescents actually received the invitation to participate (eg, they may have been absent from school when the invitations were handed out). It is therefore plausible that the true non-participation rate is somewhat lower. Furthermore, in PANCS2, 34.8% of the fathers and 44.6% of the mothers of those included in our cross-sectional study sample had completed higher education (high SES). This is similar to the general Norwegian population of men (34.3%) and women (46.8%) aged 30-49 in 2011 (~85% of parents in PANCS2 were 30-49 years old),[34] indicating that the study sample in PANCS2 is representative with regard to SES. We have no reason to believe that this would be different in 2005-2006, considering that the participation rate was higher in PANCS1 than in PANCS2.

Of those invited, 34.7% chose not to participate in the longitudinal part of the study, which could be expected based on attrition rates reported in similar studies.[32] Compared to those lost to follow-up, those included in the longitudinal study sample had somewhat lower baseline levels of BMI and higher levels of MVPA (girls only). However, overall PA and VO2-peak (data not shown) did not differ significantly. Considering the very high participation rate among 9-year-olds in PANCS1 (88.8%), this indicates good generalizability of the results.

Another strength of the study is that 90% of both children and adolescents included in the study samples wore their accelerometers for an average of >700 min/d, which indicates that the vast majority of their awake time was monitored. Furthermore, only 6.7% wore the monitor for <3 days. However, we do acknowledge the known limitations with accelerometry. Because the participants wore the monitors on their hip, and because they are not waterproof, it is unavoidable that PA intensity due to upper body movements (eg, throwing), load carrying activities (eg, carrying a backpack), other activities with little vertical hip movement (eg, cycling), and water-based activities is underestimated.

The present study investigates whether ST and PA differed in 2005-2006 and 2011-2012 among 9- and 15-year-olds, and the magnitude of intra-individual change in ST and PA between age 9 and 15 years. Although this provides valuable information, we acknowledge that important information is also lost when ST and PA are assessed at two time points only. For example, we do not know the PA levels of children and adolescents in 2007 and 2009, and we do not know whether the age-related decline in PA is linear from age 9 to 15 years.

Lastly, because the ActiGraph model used in PANCS1 (CSA 7164, piezoelectric bimorph beam accelerometer) uses a different accelerometer than the ActiGraph models used in PANCS2 (GT1M/GT3X+, solid-state monolithic accelerometer), the results should be interpreted with some caution. Although some studies have concluded that they yield comparable outputs,[35-37] others have suggested that overall PA expressed as CPM is higher from the older CSA 7164 in combination with less time identified as sedentary and more time as LPA.[38,39] Corder et al.[38] suggested that the two models are comparable with regard to MVPA, but that a correction factor of 0.91 should be applied to the mean CPM output from the CSA 7164 model when comparing with newer models. However, because there is currently no consensus whether adjustments improve the comparability between ActiGraph versions, and because adjusting mean CPM is complicated by the observed non-systematical difference in accelerometer output across the different intensity categories,[39] we decided to present our data without any adjustments. Nevertheless, if we adjust for the intergeneration difference in mean CPM suggested by some,[38,39] mean CPM in 9- and 15-year-olds did not differ significantly in 2005-2006 and 2011-2012, and the longitudinal decline in mean CPM from age 9 to 15 years was somewhat smaller. As an example, the secular decline in mean CPM (adjusted for age, measurement month and SES) observed between 2005-2006 and 2011-2012 among 9-year-old girls changes from −87.8 (95% CI: −134.6, −41.0, $P<.001$) to −25.6 (95% CI: −69.6, 18.4, $P=.254$) when the CPM values of the 2005-2006 sample are adjusted by the suggested factor of 0.91.

4.4 | Perspective

The prevalence of children and adolescents meeting the Norwegian PA recommendations was similar in 2005-2006 and 2011-2012. However, our data might indicate that both children and adolescents in 2011-2012 substituted time spent in light PA for time spent sedentary. Furthermore, our results showed that from age 9 to 15 years, time spent in MVPA reduced by more than 25%, and time spent sedentary increased by 20 percentage points.

Since the millennium, knowledge and awareness of the importance of a sufficient PA level during childhood and adolescence has increased. Because ~20% of 9-year-olds and ~50% of 15-year-olds do not achieve the recommended levels of daily MVPA, and no improvement in these numbers was observed between 2005-2006 and 2011-2012, our results are a cause for concern. Joint determined efforts are highly warranted if the Norwegian government wants to fulfill its obligation to reduce physical inactivity by 10% by the year 2025.[40]

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Paper II

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ORIGINAL ARTICLE

Cross-sectional and prospective associations between physical activity, body mass index and waist circumference in children and adolescents

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Summary

Objective

To study the cross-sectional and prospective associations between physical activity (PA) of different intensities, body mass index (BMI) and waist circumference (WC) in children and adolescents using isotemporal substitution modelling.

Methods

Physical activity (accelerometry), BMI and WC were assessed in 6- (n = 970), 9- (n = 2,423) and 15-year-olds (n = 1,544) in 2005/2006 and 2011/2012. Participants aged 9 years in 2005/2006 were followed prospectively to 2011/12 (age 15). Associations between PA of different intensities (light, moderate and vigorous), BMI and WC were examined using isotemporal substitution models.

Results

Substituting 10 min per day of sedentary time with light PA was associated with higher WC (0.17 to 0.29 cm, $p \leq 0.003$)) in all age groups. Substituting 10 min per day of sedentary time with moderate PA was associated with lower WC in 6- and 9-year-olds (−0.32 to −0.47 cm, $p \leq 0.013$)). Substituting 10 min per day of sedentary time with vigorous PA was associated with lower WC in 9- and 15-year-olds (−1.08 to −1.79 cm, $p \leq 0.015$)). Associations were similar with BMI as the outcome. In prospective analyses, substituting sedentary time with light, moderate or vigorous PA at age 9 was not associated with BMI or WC at age 15.

Conclusion

Substituting sedentary time with moderate PA appears favourably associated with adiposity in children, whereas vigorous PA may be required in adolescents. Cross-sectional associations were not replicated in prospective analyses.

Keywords: Accelerometer, body mass index, physical activitysedentary timewaist circumference.

Introduction

The prevalence of overweight and obesity among children and adolescents has increased worldwide over the last 30 years (1). Because adiposity is positively associated with cardio-vascular disease risk already at a young age (2), prevention of childhood and adolescent adiposity needs high priority (3). A number of studies have found higher levels of physical activity (PA) to be favourably associated with adiposity in children and adolescents (4–6), and PA is therefore advocated to play a key role in the prevention of excessive weight gain during childhood and adolescence (7).

Because the amount of time in a day, or in any given time period, is always limited and finite, spending time on one activity (e.g. watching TV) displaces time that could be spent doing other activities (e.g. playing soccer). I.e. it is not possible to add 10 min of moderate-to-vigorous PA (MVPA) to a day without displacing 10 min from other components of PA. However, typical models used in observational studies examining associations between PA and adiposity do not address the isotemporal nature in which different components of PA occur. As a result, associations between PA and adiposity from commonly used models do not reflect how varying distributions of different components of PA might have heterogeneous effects on adiposity. As an example, the beta coefficient from a traditional linear regression model used to investigate the association between BMI and moderate PA (MPA) might be −0.05. I.e. persons accumulating 35 min per day of MPA have 0.5 kg m^{-2} lower BMI than persons accumulating 25 min per day of MPA. However, this beta coefficient does not take into account the daily amounts of sedentary time (ST), light PA (LPA) and vigorous PA (VPA). Thus, it is unknown how big the difference in ST, LPA and VPA is between persons accumulating 35 min per day of MPA and persons accumulating 25 min per day of MPA. Recently, however, isotemporal substitution modelling has emerged as a method to examine how substitution of time in one behaviour with an equal amount of time in another associates with adiposity and other health markers (8).

Some recent studies that have used isotemporal substitution modelling indicate that substituting ST with MVPA is favourably associated with adiposity in children (9–13), but not in adolescents (11). However, whether substituting ST with LPA associates with adiposity in children and adolescents remains unclear.

Further, few previous studies have examined isotemporal substitution of ST with time spent in PA of different intensities prospectively (12). These authors observed that substituting ST with MVPA at age 10 years was favourably associated with adiposity at age 11.5 years. However, it remains to be determined whether this association persists over longer periods.

In the Physical Activity among Norwegian Children Study (PANCS) (14), anthropometric and PA data were collected from nationally representative samples of children and adolescents in 2005/2006 (PANCS1) and 2011/2012 (PANCS2), a sub-sample of which participated in both PANCS1 (age 9) and PANCS2 (age 15). Therefore, the aim of this study was to investigate the associations between PA and markers of adiposity using isotemporal substitution modelling in cross-sectional and prospective analysis with a 6-year follow-up.

Methods

Participants

In PANCS1, nationally representative, samples of 9- and 15-year-olds were recruited using a cluster sampling technique with schools as the primary unit. When a school agreed to participate, all fourth and tenth graders were invited to take part in the study. In PANCS2, nationally representative, samples of 6- and 9-year-olds were recruited using the same cluster sampling technique as in PANCS1, whereas 15-year-olds were invited either based on previous participation in PANCS1 at age 9 (prospective sample) or from a random sample of lower secondary schools that had previously participated in PANCS1 (cross-sectional sample) (Figure S1).

The Regional Committee for Medical Research Ethics approved PANCS1, and the Norwegian Social Science Data Services approved both studies. Written informed consents were obtained from all participants and their primary guardians before the start of both data collections.

Anthropometrics

Trained personnel measured height to 0.1 cm (wall-mounted measuring tape), weight to 0.1 kg (Seca 770 and 877 scales (SECA GmbH, Hamburg, Germany)) and waist circumference (WC) to 0.1 cm (minimum circumference between the lowest rib and the iliac crest), and calculated body mass index (BMI (kg m^{-2})). All the anthropometric measurements were performed twice, and the average of the two measurements was recorded. In PANCS1, the participant wore underwear during the measurements, whereas in PANCS2, the participants wore gym shorts and a t-shirt. To accounts for this, 0.3 kg was subtracted from the participants' weight in the latter study. Body mass index criteria from the International Obesity Task Force (15) and the WHO (16) were used to find the proportion of participants affected by overweight and obesity.

Physical activity

Physical activity and ST were assessed using hip-worn ActiGraph accelerometers (ActiGraph, LLC, Pensacola, Florida, USA). In PANCS1, the CSA 7164 model was used, and the participants were instructed to wear the monitor for four consecutive days, including two weekend days. In PANCS2, the GT1M and GT3X+ models were used, and the participants were instructed to wear the monitor for seven consecutive days. The participants were instructed to remove the monitor for sleep and water-based activities only.

The accelerometers were initialized to start recording at 06:00 on the day after the participants received them, and to sampled activity counts in 10-s epochs. To initialize the monitors and to download the accelerometer files, the ActiLife software (ActiGraph, LLC, Pensacola, Florida, USA) was used. For further processing, KineSoft (v3.3.76; KineSoft, Rothesay, New Brunswick, Canada) was used. After exclusion of data recorded from 00:00 to 06:00 and intervals of ≥20 consecutive minutes with no activity recorded, files with ≥2 d consisting of ≥480 min d^{-1} of activity recordings were deemed eligible for analysis. Cut-points of <100, 100–1,999, 2,000–5,999 and ≥6,000 counts per minute (CPM) were used to categorize the accelerometer data into ST, LPA, moderate PA (MPA) and vigorous PA (VPA), respectively (17).

Analysis

All statistical analyses were performed using Stata 13.1 (StataCorp. 2013. Stata Statistical Software: TX: StataCorp LP.). Sex differences, differences between age groups, changes from age 9 to 15 and associations between PA, BMI and WC were analysed using linear and logistic regression. Because the participants were recruited using the aforementioned cluster sampling technique, Statas *xtreg re* command (generalized least-square random effects) was used, with school declared (xtset) as the panel. School was also incorporated as a cluster variable in all models using the *vce cluster* option to obtain robust variance estimations. In the prospective analyses, the school participants attended at baseline was used as the cluster variable.

For the cross-sectional analyses, data collected from 9- and 15-year-olds in PANCS1 and PANCS2 were pooled (6-year-olds were only included in PANCS2 (Figure S1)). To quantify the cross-sectional and prospective associations between PA of the different intensities (LPA, MPA and VPA), BMI and WC, an isotemporal substitution approach to the linear regression models was used. Isotemporal substitution modelling has been described in detail elsewhere (8). In short, all quantifiable components of a behaviour, e.g. daily macronutrient intake or PA, are entered into the model simultaneously together with the sum of all components (i.e. total caloric intake or accelerometer wear time), except for the component to be substituted. In the present study, summing time spent in all components of PA (ST + LPA + MPA + VPA = accelerometer wear time) renders time isotemporal (constant). By excluding ST from the model, but keeping accelerometer wear time, the beta coefficients for LPA, MPA and VPA represent the theoretical effect of displacing a fixed duration of ST with a fixed duration of LPA, MPA and VPA, respectively (11,12). To obtain beta coefficients representing 10 min d^{-1} substitutions, each component of PA was multiplied by a constant of 0.1 before they were entered into the models. The dependent (BMI and WC) and independent (LPA, MPA and VPA) variables were entered into the models in their continuous form.

In initial analyses, interaction terms were fitted to assess whether associations were modified by sex. Significant sex by MPA interactions were found in analyses of 6-year-olds ($p \leq 0.039$). No interactions were found in analyses of 9- or 15-year-olds, or in the prospective analyses. Consequently, analyses of 6-year-olds were stratified by sex, whereas all other analyses were performed combining girls and boys, but adjusting for sex. Because assessments were performed throughout the school year, all analyses were adjusted for age. Prospective analyses were also adjusted for the baseline value of the dependent variables (BMI and WC, respectively) and follow-up time. Socioeconomic status (SES) was included as a covariate in preliminary analyses; however because inclusion of this variable did not alter the results to any appreciable extent, it was excluded from our final models. All analyses were also run with BMI and WC *z*-scores as dependent variables (results presented as Supporting Information (Table S1)).

Last, multicollinearity was checked using Statas *correlate* (pairwise correlation) and *collin* commands (variance inflation factors and tolerance statistics). Multicollinearity is likely to be present if the pairwise correlation between two variables is >0.8 (highest observed, $r = 0.53$), if the mean variance inflation factor is >6 (highest observed mean = 1.39), if the highest individual variance inflation factor is >10 (highest observed = 1.59) or if the tolerance statistic is <0.1 (all observed to be >0.62).

Results

Cross-sectional analyses

We invited 2,818 and 5,603 youth to participate in PANCS1 and PANCS2, respectively. Of these 5,897 (70.0%) signed an informed consent and agreed to participate. The participation rates for 6-, 9- and 15-year-olds were 56.4, 79.9 and 67.6%, respectively.

Table 1 displays descriptive characteristics of the study sample by age group and sex. Body mass index did not differ significantly between girls and boys within any of the three age groups ($p \geq 0.059$). We found no difference in WC between girls and boys in the two younger age groups ($p \geq 0.390$); however, WC was significantly larger in boys than in girls in 15-year-olds ($p < 0.001$).

With the exception of VPA in boys ($p = 0.406$), ST and time in PA of different intensities differed significantly between the three age groups in both genders (adjusted

Table 1 Descriptive characteristics (mean (SD)) of the cross-sectional study samples of 6-, 9- and 15-year-olds

	6-year-olds		9-year-olds		15-year-olds	
	Girls	Boys	Girls	Boys	Girls	Boys
n[a]	495–512	475–494	1,198–1,219	1,225–1,253	778–850	766–824
Age (years)	6.6 (0.4)	6.6 (0.4)	9.6 (0.4)	9.6 (0.4)	15.3 (0.5)	15.4 (0.6)[b]
Height (cm)	120.9 (5.4)	122.2 (5.8)[b]	138.2 (6.6)	139.3 (6.6)[b]	165.3 (6.4)	174.2 (7.7)[b]
Weight (kg)	23.8 (4.2)	24.0 (3.7)	33.8 (6.9)	33.9 (6.7)	57.7 (9.2)	63.5 (12.4)[b]
BMI (kg m^{-2})	16.2 (2.0)	16.0 (1.6)	17.6 (2.7)	17.4 (2.6)	21.1 (3.0)	20.9 (3.5)
Overweight (%)[c]	18.4	12.8[b]	21.8	17.7[b]	20.3	13.9[b]
Obese (%)[c]	4.4	2.7	4.1	4.2	2.6	3.8
Overweight (%)[d]	22.6	20.6	27.1	25.8	17.2	19.0
Obese (%)[d]	5.7	4.3	6.2	8.1[b]	2.2	6.1[b]
WC (cm)	54.4 (5.0)	54.8 (4.2)	61.1 (7.3)	61.5 (6.9)	71.1 (7.1)	74.2 (9.1)[b]
ST (min d^{-1})	392.3 (48.9)	378.4 (51.0)[b]	452.9 (62.9)	432.9 (68.5)[b]	565.6 (72.5)	551.2 (77.6)[b]
LPA (min d^{-1})	250.6 (33.7)	258.5 (33.1)	244.2 (42.6)	249.2 (46.2)	169.2 (44.9)	179.2 (47.0)[b]
MPA (min d^{-1})	73.7 (17.5)	92.2 (22.6)[b]	65.4 (18.9)	82.5 (24.6)[b]	53.4 (20.0)	58.2 (22.3)[b]
VPA (min d^{-1})	7.7 (4.8)	7.7 (5.0)	7.4 (5.0)	9.4 (6.8)[b]	6.0 (5.8)	8.8 (7.9)[b]
WT (min d^{-1})	724.3 (53.1)	736.9 (51.7)[b]	769.8 (60.1)	774.0 (60.8)	794.3 (74.6)	797.5 (80.4)

[a]All the participants displayed had valid assessments of physical activity, but the n varies for BMI and WC.
[b]Significantly different from girls within the same age group ($p \leq 0.035$).
[c]Based on age- and sex-specific BMI cut-points from the International Obesity Task Force (overweight includes obese) (15).
[d]Based on age- and sex-specific BMI cut-points from the WHO (overweight includes obese) (16).
BMI, body mass index; WC, waist circumference; ST, sedentary time; LPA, light physical activity; MPA, moderate physical activity; VPA, vigorous physical activity; WT, accelerometer wear time.

for accelerometer wear time, $p \leq 0.001$). Six-year-olds spent less time sedentary and more time in PA than 9- and 15-year-olds ($p < 0.001$); 9-year-olds spent less time sedentary and more time in PA than 15-year-olds ($p < 0.001$).

Table 2 displays the beta coefficients and 95% confidence intervals from the isotemporal substitution models. BMI: Substituting ST with LPA was associated with a higher BMI in 6-year-old girls and boys ($p \leq 0.012$), and in 9-year-olds ($p < 0.001$), but not in 15-year-olds ($p = 0.206$). Substituting ST with MPA was associated with a lower BMI in 6-year-old girls and 9-year-olds ($p \leq 0.034$), but not in 6-year-old boys or 15-year-olds ($p \geq 0.152$). Substituting ST with VPA was associated with a lower BMI in 9- and 15-year-olds ($p < 0.001$), but not in 6-year-olds ($p \geq 0.099$). WC: Substituting ST with LPA was associated with higher WC in 6-year-old girls, 9- and 15-year-olds ($p \leq 0.002$), but not in 6-year-old boys ($p = 0.078$). In 6-year-old girls and 9-year-olds, substituting ST with MPA was associated with lower WC ($p \leq 0.013$). This was not observed in other age- or sex groups ($p \geq 0.580$). Substituting ST with VPA was associated with lower WC in 9- and 15-year-olds ($p \leq 0.015$), but not in 6-year-olds ($p \geq 0.084$). In sensitivity analyses, substituting WC with waist-to-height ratio (18) did not change any of the observed associations (data not shown).

Prospective analyses

Of the 1,306 participating in PANCS1 at age 9 years, 1,119 were found and invited to participate in PANCS2 at age 15 years. Of these, 731 (65.3%) agreed to participate. Table 3 displays descriptive characteristics of the prospective study sample at baseline and follow-up. Of those with valid PA, BMI and WC assessments at baseline, 503 (239 girls) and 476 (223 girls) had valid BMI and WC assessments at follow-up, respectively.

From baseline to follow-up, BMI and WC increased significantly in girls and boys ($p < 0.001$). These changes were accompanied by a significant increase in ST and significant decreases in LPA, MPA and VPA ($p < 0.001$). However, substituting ST with LPA, MPA or VPA at age 9 was not associated with BMI ($p \geq 0.059$) or WC ($p \geq 0.321$) at age 15 (Table 2).

Discussion

Results from the cross-sectional analyses suggest favourable associations when substituting ST with MPA and VPA, but also somewhat counter intuitive, unfavourable associations when substituting ST with LPA. However, results from the prospective analyses do

Table 2 Cross-sectional and prospective associations between 10 min day^{-1} substitutions of sedentary time, body mass index and waist circumference

Replacing 10 min d^{-1} of sedentary time with 10 min d^{-1} of:	*n*	Body mass index (BMI (kg m^{-2})) β (95% CI)	*n*	Waist circumference (WC (cm)) β (95% CI)
Cross-sectional analyses[a]				
6-year-old girls				
Light PA	505	0.10 (0.04, 0.17)**	495	0.29 (0.13, 0.45)**
Moderate PA	505	−0.18 (−0.35, −0.01)*	495	−0.47 (−0.85, −0.10)*
Vigorous PA	505	−0.21 (−0.58, 0.16)	495	−0.15 (−1.20, 0.90)
6-year-old boys				
Light PA	485	0.08 (0.02, 0.15)*	475	0.15 (−0.02, 0.33)
Moderate PA	485	0.03 (−0.05, 0.12)	475	0.06 (−0.16, 0.29)
Vigorous PA	485	−0.32 (−0.71, 0.06)	475	−0.79 (−1.68, 0.10)
9-year-olds				
Light PA	2,445	0.05 (0.02, 0.07)**	2,423	0.17 (0.10, 0.25)**
Moderate PA	2,445	−0.08 (−0.15, −0.02)*	2,423	−0.32 (−0.46, −0.18)**
Vigorous PA	2,445	−0.83 (1.04, −0.63)**	2,423	−1.79 (−2.36, −1.23)**
15-year-olds				
Light PA	1,592	0.03 (−0.02, 0.07)	1,544	0.17 (0.06, 0.28)**
Moderate PA	1,592	0.06 (−0.02, 0.15)	1,544	0.02 (−0.20, 0.24)
Vigorous PA	1,592	−0.56 (−0.87, −0.25)**	1,544	−1.08 (−1.94, −0.21)*
Prospective analyses[b]				
Light PA	503	0.05 (−0.00, 0.11)	476	0.07 (−0.08, 0.23)
Moderate PA	503	−0.05 (−0.14, 0.04)	476	−0.09 (−0.37, 0.20)
Vigorous PA	503	0.16 (−0.17, 0.49)	476	−0.43 (−1.29, 0.42)

[a]Adjusted for sex (not in analyses of 6-year-olds), age and accelerometer wear time.
[b]Adjusted for sex, age at baseline, follow-up time and BMI/WC at baseline.
*$p \leq 0.040$.
**$p \leq 0.003$.
CI, confidence interval; PA, physical activity.

Table 3 Descriptive characteristics (mean (SD)) of the prospective study sample at baseline (9-year-olds) and follow-up (15-year-olds)

	Girls		Boys	
	Baseline	Follow-up	Baseline	Follow-up
n[a]	223–239	223–239	253–264	253–264
Age (years)	9.6 (0.4)	15.2 (0.7)[b]	9.7 (0.4)	15.2 (0.7)[b]
Height (cm)	138.3 (6.8)	165.3 (6.2)[b]	139.9 (6.0)	173.9 (8.0)[b]
Weight (kg)	33.3 (6.7)	57.7 (9.5)[b]	33.5 (5.8)	61.8 (10.9)[b]
BMI (kg m^{-2})	17.3 (2.6)	21.1 (3.1)[b]	17.0 (2.1)	20.4 (2.9)[b]
Overweight (%)	15.9	22.9[b]	13.3	10.6
Obese (%)	3.3	3.8	1.8	1.1
WC (cm)	62.2 (7.0)	69.0 (6.2)[b]	61.3 (6.6)	72.5 (7.5)[b]
ST (min d^{-1})	426.3 (64.2)	580.2 (61.0)[b]	416.6 (70.4)	556.7 (73.8)[b]
LPA (min d^{-1})	266.6 (41.2)	152.7 (35.3)[b]	272.8 (48.6)	167.3 (39.4)[b]
MPA (min d^{-1})	67.5 (19.8)	55.2 (18.7)[b]	84.3 (25.6)	61.8 (22.6)[b]
VPA (min d^{-1})	9.4 (5.5)	5.5 (5.4)[b]	11.5 (7.5)	8.7 (7.9)[b]
WT (min d^{-1})	769.9 (63.7)	793.5 (70.5)	785.1 (59.5)	794.5 (78.1)

[a]All the participants displayed had valid assessments of physical activity at both time points, but the *n* varies for BMI and WC.
[b]Significant change from baseline ($p < 0.007$).
BMI, body mass index; WC, waist circumference; ST, sedentary time; LPA, light physical activity; MPA, moderate physical activity; VPA, vigorous physical activity.

not confirm the cross-sectional associations observed and do not indicate that substituting ST with LPA, MPA or VPA during childhood is associated with development of adiposity between childhood and adolescence.

Compared to previous studies using isotemporal modelling to study the association between PA and adiposity in children and adolescents, our finding that substituting ST with LPA is positively associated with BMI and WC is surprising. Others, using both field-based (BMI, WC) and more comprehensive measures of adiposity (dual-energy X-ray absorptiometry (DXA)), have found either no association (10–13) or a negative association (9). However, recently presented results from the Iowa Bone Development Study have actually also indicated a positive association between LPA and adiposity (19). Other behaviours positively associated with BMI and WC may be common during LPA, e.g. consumption of energy dense snacks/beverages. This has been suggested to confound associations between TV viewing, a frequently used proxy measure for ST, and cardio-metabolic risk factors in children and youth (5,20). Similar confounding may also be present in our analyses. However, it has been shown that the classification accuracy of LPA assessed with ActiGraph accelerometers is lower than for ST and MVPA (21). Therefore, it is also possible that some of the time classified as LPA was in fact ST.

Our finding that substituting ST with MPA and/or VPA is favourably associated with BMI and WC is, to some extent, in accordance with previous studies (9–13). However, because only one previous study modelled substitution of ST with MPA and VPA separately in children (not merged into MVPA) (9), our results extend previous observations. At first glance, it might seem like the associations between MPA, BMI and WC are sex dependent in 6-year-olds, as substitution of ST with MPA was favourably associated with BMI and WC in girls, but not boys. However, this difference may be explained by the very high amount of daily MPA accumulated by boys compared to girls, and that a higher proportion of girls were classified as overweight (Table 1). Six-year-old girls and boys had similar levels of VPA, and VPA was not significantly associated with BMI or WC in either sex. In 6-year-old boys, but not girls, the 95% confidence intervals might indicate that the lack of association between VPA, BMI and WC results from a lack of statistical power.

Our finding that substitution of ST with MPA and VPA was favourably associated with BMI and WC in a dose-dependent fashion among in 9-year-olds agrees with results from a previous study in Finnish children (9). In 15-year-olds, however, our results suggest that more vigorous intensity PA is required to favourably affect BMI and WC. This difference might reflect both physiological and behavioural differences between children and adolescents that can affect adiposity (22). The lack of association between MPA, BMI and WC among 15-year-olds is supported by findings in American adolescents (11). However, that study did not model MPA and VPA separately; thus, it is unknown if the beneficial associations we observed when substituting ST with VPA translate to their study population.

None of the cross-sectional associations observed were replicated in prospective analyses. This lack of temporality is important to consider, and additional prospective analyses should investigate whether the associations between PA, BMI and WC (and other markers of adiposity) are reverse or bi-directional in children and adolescents, which has been suggested previously (5,23).

However, although our results agree with some previous studies (5,23), they contrast the one previous study using isotemporal substitution modelling to study the prospective association between PA and adiposity in children (12). They also contrast some other previous studies that used other analytical approaches (24,25). This discrepancy may possibly relate to the age of participants and the duration of follow-up. Even though our results indicate that childhood PA is a poor predictors of adolescent BMI and WC, it is possible that PA measured during early childhood can predict adiposity later in childhood (24), and that PA can predict adiposity in the short term (e.g. follow-up $\leq$2 years) (4,12,25). However, it is also possible that more sensitive adiposity measures (e.g. DXA) than used in the present study are necessary to detect prospective associations between childhood PA and adolescent adiposity (25,26). Last, it is important to consider that the exposure only represents a snapshot of habitual PA, and that the number of participants included in the prospective analyses was rather moderate.

A number of studies have found unfavourable associations between adiposity and cardio-metabolic risk in children and adolescents, and a recent systematic review concluded that whatever the definition used for abdominal adiposity and whatever the methods used for anthropometric measurements, central body fat deposition in children and adolescents increases cardio-metabolic risk (27). However, limited data on the magnitude of change in cardio-metabolic risk factors associated with absolute incremental change in BMI and WC (i.e. $\pm$1 kg m^{-2} and $\pm$1 cm) in children and adolescents are available. Therefore, it is difficult to translate the observed differences in adiposity markers associated with substitution of ST for MPA and VPA to small, medium or large clinical importance. However, the intraclass correlation coefficient for within-individual differences in accelerometer assessed PA is approximately 0.5 (28); thus, the true magnitude of the associations may be at least twice as strong as the associations observed (if we assume that all measurement error stems from within-individual variability).

Previous studies investigating how substituting ST with MPA, VPA or MVPA associates with adiposity have modelled 10, 15, 30 and 60 min d^{-1} substitutions (9–13). Unsurprisingly, modelling larger amounts of time substituted results in larger regression coefficients (multiplying the components of PA by a factor of 0.3 or 0.6 rather than 0.1 before entering them into linear models renders exactly 3 and 6 times larger beta coefficient). However, it is debatable whether 30–60 min d^{-1} substitutions are realistic, and 10 min d^{-1} substitutions may be more achievable. Mean daily VPA was considerably lower than mean daily MPA in all three age groups, but compared to substituting ST with MPA, substituting ST with VPA was associated with much larger (theoretical) decreases in BMI and WC in 9-year-olds. This suggests that efforts made to promote even small daily increases in VPA are important. The favourable associations observed when substituting ST with VPA, but not MPA, in 15-year-olds, support this further. To facilitate comparisons of our results with results from other studies that have modelled larger substitutions, we present results from 30 and 60 min d^{-1} substitutions in Tables S2 and S3 (Supporting Information).

One of the strengths of this study is the large, nationally representative samples of children and adolescents. Further, our study is novel as we used isotemporal substitution modelling to examine how substituting ST for an equal amount of LPA, MPA or VPA during childhood associates with BMI and WC measured 6 years later during adolescence. The accelerometry used to assess ST, LPA MPA and VPA, and the measurement of BMI and WC are strengths, as this reduces measurement error caused by biases associated with self-report (29).

This study also has some important limitations. First, hip-worn accelerometers mainly capture ambulatory PA. Therefore, it is unavoidable that upper body movement (e.g. throwing or climbing), load carrying activities (e.g. carrying a backpack) and other activities with little vertical hip movement (e.g. cycling) is underestimated. Further, there is currently no consensus on which cut-points that best discriminate between ST, LPA, MPA and VPA in children and adolescents, and we acknowledge that choosing other cut-points might have altered the associations (30). Also, we used the same cut-points to classify PA in data collected with three different ActiGraph models, which may cause misclassification (31). However, stratifying the analyses by accelerometer model did not change the results. Last, there is no guaranty against misclassification of time spent motionless as non-wear by the wear-time algorithms applied to accelerometer data. For children, it is common to classify fairly short bouts with no activity recorded as non-wear (32), the rationale behind this being that it seems unlikely for a child to stay absolutely still for more than 10 or 20 consecutive minutes (33). Although longer bouts do increase the risk of classifying true non-wear as ST in children, short bouts may increase the risk of classifying true ST as non-wear. There is currently no consensus on what non-wear algorithm to use for children, but the combination of non-wear, valid day and number of valid days-criteria chosen in our study has been shown to give a reliable estimate of children's habitual PA (34).

Other limitations include the use of indirect measures of adiposity and that we were unable to control for putative confounding factors such as energy intake, sleep and genetic factors. Finally, because this is an observational study, it is impossible to control for things that happened before baseline. For example, a low PA level may theoretically have caused a weight gain already before the baseline measurement in the prospective analysis.

Conclusion

This study suggests that isotemporal substitution of ST with MPA and VPA is favourably associated with BMI and WC in children. In adolescents, favourable associations were only observed when ST was substituted with VPA. However, because these cross-sectional associations were not replicated in prospective analyses, we are unable to determine the direction of associations.

Conflicts of Interest Statement

No conflict of interest was declared.

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Supporting Information

Additional Supporting Information may be found online in the supporting information tab for this article.

Figure S1: Flow-chart of the study samples in the Physical Activity among Norwegian Children Studies. * 1,119 of the 1,306 9-year-olds that participated in PANCS1 were found and invited to participate in PANCS2 as 15-year-olds. ** Includes participants from the cross-sectional samples in PANCS1 and 2, and the prospective sample followed from PANCS1 to PANCS2 (data from follow-up assessments).

Table S1: Cross-sectional and prospective associations between 10 min day^{-1} substitutions of sedentary time, BMI *z*-scoresc and WC *z*-scoresc.

Table S2: Cross-sectional and prospective associations between 30 min day^{-1} substitutions of sedentary time, body mass index and waist circumference.

Table S3: Cross-sectional and prospective associations between 60 min day^{-1} substitutions of sedentary time, body mass index and waist circumference.

Paper III

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Permanent play facility provision is associated with children's time spent sedentary and in light physical activity during school hours: A cross-sectional study

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ABSTRACT

Objective: To study the associations between: 1) number of permanent outdoor play facilities per pupil and 2) the size of the outdoor play area per pupil with sedentary time and physical activity (PA) during school hours in six-, nine-, and 15-year olds. We conducted a cross-sectional study of nationally representative samples of Norwegian six- (n = 1071), nine- (n = 1421) and 15-year-olds (n = 1106) in 2011 (the Physical Activity Among Norwegian Children Study). The participation rates were 56.4%, 73.1% and 57.8% for six-, nine- and 15-year olds, respectively. We assessed PA objectively for seven consecutive days using accelerometers, the size of a school's outdoor play area (SOPA) using an online map service and the permanent play facility (PPF) provision using a standardized form during school site visits. We successfully measured SOPA and PPF in 99 schools, from which 3040 participants provided valid accelerometer data. We used generalized least-squares random-effects models with robust variance estimation to assess associations. Our results indicate that better provision of permanent play facilities may reduce sedentary time and increase time spent in light PA among six-year-olds. Permanent play facility provision was not associated with sedentary time or PA among nine- and 15-year-olds. Associations found between outdoor play area size, physical activity and sedentary time were negligible. Future research should investigate what types of permanent play facilities may be associated with physical activity in both children and adolescents.

1. Introduction

Since almost all children spend a large proportion of their awake time in school, this arena provides a unique setting for physical activity (PA) promotion. During and adjacent to the school day, children may have several opportunities to be physically active, e.g. through active travel, physical education (PE) and recess. Intervention studies aimed at promoting PA in all these settings have shown promising results (Lonsdale et al., 2013; Larouche et al., 2014; Ickes et al., 2013). However, because it is already compulsory in most schools and does not compete with academic interests (Ickes et al., 2013), recess might be a particularly attractive arena for PA promotion. Children also seem to be more physically active in school free play than during PE lessons (Sleap and Warburton, 1996), and more physically active outdoors compared with indoors (Gray et al., 2015). Unstructured free play during recess has been shown to contribute 5–40% of recommended daily PA (Ridgers et al., 2006), indicating that some schools might have a large PA promoting potential through simple, low-cost strategies.

Designing outdoor play areas that stimulate as many pupils as possible to be physically active is, however, a multifaceted process. For example, studies indicate that girls and boys use different areas of their school's outdoor play area (SOPA) when being physically active (Fjørtoft et al., 2009; Anthamatten et al., 2014), that PA levels are higher in areas with a naturalistic feel (Fjørtoft, 2004) and that colorful playground markings can increase recess PA (Blaes et al., 2013). Both the size of SOPA and the availability of permanent play facilities (PPF) are basic components of a schoolyard design, and studies indicate that both factors may be important to stimulate PA (D'Haese et al., 2013; Escalante et al., 2012; Nielsen et al., 2010). However, previous research is limited by the use of subjective measures of PA and small sample sizes (Haug et al., 2010; Ridgers et al., 2010b). Furthermore, studies investigating the association between the size and PPF content of SOPA with time spent sedentary among children and adolescents are limited. Even though debated, studies have indicated that sedentary time

Abbreviations: PA, Physical activity; PE, Physical education; CPM, Counts per minute; LPA, Light physical activity; MVPA, Moderate-to-vigorous physical activity; SES, Socioeconomic status; CI, Confidence interval; BMI, Body mass index; SOPA, School's outdoor play area(s); PPFs, Permanent play facilities.

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might pose a negative effect on cardiovascular risk factors already at a young age (Healy and Owen, 2010). Therefore, further research is necessary to identify the importance of the size and PPF content of SOPA for both PA and sedentary time.

Therefore, the aim of this study was to assess the associations between: 1) number of permanent play facilities and 2) the size of the outdoor play area with objectively measured sedentary time and physical activity during school hours in a representative sample of pupils from Norwegian schools.

2. Materials and methods

2.1. Participants

The participants in this cross-sectional study, the Physical Activity Among Norwegian Children Study, were nationally representative samples of six-, nine- and 15-year-olds. Statistics Norway randomly selected the cohort using cluster sampling, with school as the primary unit. When a school agreed to participate, we invited all pupils in first, fourth or tenth grade to participate. In total, 5757 pupils from 107 schools were invited. We obtained written informed consent from 3598 participants and their primary guardians, yielding participation rates of 56.4%, 73.1% and 57.8% for six-, nine- and 15-year-olds, respectively. The Regional Committee for Medical Research Ethics and the Norwegian Social Science Data Services reviewed and approved the study. We conducted the study according to the Helsinki declaration.

2.2. Anthropometrics

We measured weight and height to the nearest 0.1 kg (Seca 877, SECA GmbH, Hamburg, Germany) and 0.1 cm (wall-mounted measuring tape), respectively, while the participants wore light clothing and no shoes. Body mass index (BMI) was calculated as kg/m^2.

2.3. Physical activity

We measured PA using ActiGraph accelerometers (models GT1M and GT3X+; ActiGraph, LLC, Pensacola, Florida, USA). Children's free-living PA measured with ActiGraph accelerometers has previously been shown to correlate moderately well with activity energy expenditure measured by doubly labeled water ($r = 0.66$, $p < 0.001$) (Ekelund et al., 2001). The participants were fitted with the accelerometers on their right hip during school visits, and instructed to wear the monitor during all waking hours for seven consecutive days, except during showering and bathing. Using the Actilife software (ActiGraph, LLC, Pensacola, Florida, USA), we initialized the accelerometers to sample vertical accelerations (30 Hz), and to start recording at 06:00 on the day after the monitors were attached in order to eliminate reactivity-bias (Dossegger et al., 2014). We used KineSoft (KineSoft Software, Rothesay, New Brunswick, Canada) to analyze the accelerometer files.

An epoch length of 10 s was used, which has been deemed suitable for children (McClain et al., 2008). We defined non-wear as intervals ≥20 consecutive minutes with no activity recordings, and wear time by subtracting non-wear from school hours. In Norway, school normally starts between 8:00 and 9:00 and ends between 13:00 and 14:45, depending on school and grade. To ensure that we only included school hours, we defined schooldays as 9:00–13:00 for six- and nine-year-olds and 9:00–14:00 for 15-year-olds. These periods include morning-, lunch- and afternoon recess for all grades. We excluded all schooldays with ≥60 min of non-wear and included participants if they had accumulated ≥2 valid schooldays of accelerometer data. We collected all data from March to December in 2011 (no measures in July due to summer holidays). Measurements were evenly distributed across the school year, with the exception of August and December during which only 82 and 95 pupils were measured, respectively.

We used counts·min^{-1} (CPM) as a measure of overall school PA. We calculated CPM by dividing the total number of school day counts by the total number of school day wear minutes. To investigate time spent sedentary, in PA of light intensity (LPA) and of moderate-to-vigorous intensity (MVPA), we used cut-points of <100 CPM (1–1.5 METs), 100–1999 CPM (1.6–2.9 METs) and ≥2000 CPM (≥3 METs), respectively (Andersen et al., 2006).

2.4. Play facilities/area size

During school visits, the research team registered the number of PPFs using a standardized form. Subsequently, we calculated the number of PPFs per pupil. To measure the size of SOPA we used a polygon measurement tool and updated electronic maps from the Norwegian Mapping Authority (finn.no, 2011). We calculated SOPA by subtracting areas of buildings, car parks and other areas with car traffic from the school's total outdoor area, and then calculated the SOPA per pupil. Others have used similar methods (Pagels et al., 2014; Ridgers et al., 2010a; Nilsen, 2014).

Through interviews with teachers, we received information on recess period organization potentially influencing the availability of space and play facilities (e.g. access to areas outside school property and sectioning of SOPA during recess).

2.5. Socioeconomic status

We used the highest education level of the participant's parents (data from Statistics Norway) as a proxy for socioeconomic status (SES) and computed four SES groups: low (primary school, lower secondary school, vocational high school), middle low (secondary school/high school), middle high (undergraduate degree) and high (graduate degree).

2.6. Sample size calculations

We based the sample size calculations on the ability to detect subgroup differences in CPM. With respect to this, 516 individuals in each age and sex group allowed us to detect subgroup differences of 7% using a two-tailed test ($1 - \beta = 0.90$; two-tailed $\alpha = 0.05$). Because of cluster sampling, we incorporated a design effect of 1.1, yielding a final target sample size of 567 individuals in each age and sex group.

2.7. Statistical analysis

We performed all statistical analyses using Stata 13.1 (StataCorp. 2013. Stata Statistical Software: TX: StataCorp LP.). We used independent samples *t*-test to investigate sex differences, and one-way ANOVA with Bonferroni corrections to assess differences between the three age groups. For our main analyses, we ran all the models separately for the different age groups. To account for cluster sampling, we used GLS-re models with robust variance estimation. Initially, we entered the interaction terms *sex* ∗ *number of PPFs* and *sex* ∗ *play area size*. The interaction terms were not statistically significant. Consequently, we did not stratify the main analyses by sex but rather included sex as a covariate.

We adjusted all analyses for accelerometer wear time (except analyses of CPM), measurement month, sex, and SES, and the dummy variables "access to areas outside school property", "sectioning of play areas", "recess at different time points for different classes" and "allowed to spend recess indoors". We also adjusted for number of PPFs in analyses with the size of SOPA as the independent variable.

3. Results

Of the 3598 participants, 3040 from 99 schools met the inclusion criteria. Because of construction work, we did not get valid measurements in three schools ($n = 212$). The remainder of the excluded participants did not provide valid PA measurements (n = 346). Table 1 displays descriptive characteristics of the study sample. Participants meeting the inclusion criteria were similar to those who did not in terms of age and BMI. However, a higher proportion of the excluded six- and nine-year-old participants were categorized in the two lowest SES categories. In general, there were only small differences in BMI and SES between boys and girls within the age groups.

3.1. Physical activity

The participants provided 4.2 ± 0.9 valid school days of PA measurements (mean ± SD). Table 2 displays the participants' school day PA and sedentary time. School day PA and sedentary time were significantly different between all the age groups ($p < 0.001$) and significantly different between girls and boys within the age groups ($p < 0.001$). For the six-, nine- and 15-year-olds, the mean ± SD proportions of weekday time spent sedentary accumulated during school hours were 31 ± 5%, 31 ± 5% and 38 ± 7%, respectively. The mean ± SD proportions of weekday MVPA accumulated during school hours were 36 ± 8%, 35 ± 10% and 36 ± 15%, respectively.

3.2. Permanent play facilities

We registered >50 unique PPFs across the participating schools. Swings (94.5%), climbing frames (87.9%), soccer goals (85.5%) and sand boxes (79.5%) were the most common permanent play facilities in primary schools. The most common permanent play facilities in lower secondary schools were basketball hoops (85.3%), soccer goals (79.0%) and beach volleyball nets (33.5%). The absolute number of PPFs and the number of PPFs per pupil in primary schools were significantly higher than in lower secondary schools ($p < 0.001$) (Table 3).

The participants' overall PA and time spent in MVPA were not associated with the number of PPFs per pupil. Among six-year-olds, however, there was a significant negative association between the number of PPFs per pupil and time spent sedentary and a significant positive association between the number of PPFs per pupil and time spent in LPA. These associations translate to daily changes in time spent sedentary and in LPA of −3.8 and 2.2 min, respectively, if the number of PPFs per pupil increased from 0.1 to 0.2 (Table 4).

3.3. Outdoor play area size

The size of SOPA per pupil in primary schools was significantly larger than in lower secondary schools ($p < 0.001$) (Table 3). For the six- and nine-year-olds, we did not find an association between the size of SOPA per pupil and overall PA, LPA, MVPA or time spent sedentary. Among the 15-year-olds, we found the size of SOPA per pupil to be positively associated with LPA and negatively associated with MVPA (Table 5). These associations translate to an increase in LPA of 0.9 min/d and a decrease in MVPA of 0.4 min/d if the size of SOPA increased by $10m^2$ per pupil.

4. Discussion

The results from the present study suggest a weak association between outdoor PPF availability, time spent sedentary and time spent in LPA among six-year-olds. An increase in the number of PPFs from 0.1 to 0.2 per pupil, which equates to a doubling of PPF in an average Norwegian primary school, was associated with 3.1% less sedentary time and 2.5% more time spent in LPA during school hours. However, since the influence of PPF on sedentary time and PA is mainly restricted to recess, these weak, although statistically significant, associations may not be negligible. Primary and lower secondary schools in Norway provide approximately 60 min/day of recess (10–15 min of morning recess, 30–40 min of lunch recess and 10–15 min of afternoon recess). Although speculative, if the observed associations were in fact restricted to recess, they would translate to ~6.3% less sedentary time and ~3.6% more LPA. However, we did not observe any associations between sedentary time and PA with PPF in nine-year-olds. This may be explained by differences between age groups in time spent outdoors during school hours. In the Norwegian school system part of the taught classes in the first grade are outdoor classes, possibly contributing differences in observed associations.

Studies investigating the isolated association between PPF provision and objectively measured sedentary time in children are limited. Results from Ridgers et al. (2010a, 2010b) support our finding that PPF provision is negatively associated with sedentary time during school hours (Ridgers et al., 2010a). In their study, children without access to fixed equipment during recess engaged in 8.2% more sedentary activity than children provided with fixed equipment.

We did not find PPF provision to be associated with overall PA or MVPA in children. This is supported by two studies conducted in Australia, where no association between equipment availability (other than balls) and MVPA (Zask et al., 2001) or energy expenditure (Harten et al., 2008) was observed. In contrast, Ridgers et al. (2010a, 2010b) suggested a positive association between PPF provision and MVPA (Ridgers et al., 2010a). The latter is also supported by three other cross-sectional studies that used accelerometers to assess PA (Nielsen et al., 2010, 2012; Taylor et al., 2011). However, the strength of the associations reported in these studies varied considerably (Nielsen et al., 2010; Taylor et al., 2011). Consequently, studies differ in their conclusions with regard to the actual importance of PPF provision for children's PA during school hours.

Contradictory results may reflect actual differences in the everyday life of children in different study populations, e.g. due to different school policies regarding PA. However, in three of the studies reporting an

Table 1
Characteristics of the study sample in the Physical Activity Among Norwegian Children Study (2011) by age and sex (n = 3040).

	6-year-olds		9-year-olds		15-year-olds	
	Girls	Boys	Girls	Boys	Girls	Boys
n	489	479	663	625	393	391
Age (yrs.)[a]	6.6 (0.4)	6.6 (0.4)	9.6 (0.4)	9.6 (0.4)	15.1 (0.6)	15.1 (0.6)
Height (cm)[a]	121.0 (5.5)[c]	122.2 (5.8)	138.0 (6.5)	138.7 (6.8)	164.7 (6.4)[c]	172.9 (8.0)
Weight (kg)[a,b]	23.8 (4.2)	24.0 (3.8)	33.7 (6.8)	33.9 (6.9)	57.1 (9.4)[c]	62.0 (12.0)
BMI (kg/m^2)[a]	16.2 (1.9)	16.0 (1.6)	17.6 (2.7)	17.5 (2.7)	21.1 (3.1)	20.7 (3.3)
Parents' educ. level (%)						
Low	7.5	6.8	10.8	9.0	10.9	12.7
Middle low	30.8	31.7	31.1	36.3	33.1	35.4
Middle high	45.8	45.7	43.0	40.7	39.1	37.7
High	15.8	15.9	15.0	14.0	16.9	14.3

BMI = body mass index; educ. = education.
[a] Mean (standard deviation).
[b] The weight was corrected by −0.3 kg for all participants to account for clothes.
[c] Significantly different from boys within age group (all p-values ≤ 0.001).

Table 2
Mean (SD) physical activity and minutes of time spent sedentary among Norwegian children and adolescents during school hours.[a]

	6-year-olds		9-year-olds		15-year-olds	
	Girls	Boys	Girls	Boys	Girls	Boys
n	489	479	663	625	393	391
Overall PA (CPM)[b]	765 ± 211[c,e]	845 ± 227[c]	607 ± 183[d,e]	750 ± 206[d]	358 ± 138[e]	475 ± 173
Sedentary (min/d)[b]	127 ± 18[c,e]	118 ± 20[c]	150 ± 23[d,e]	137 ± 23[d]	237 ± 36[e]	214 ± 29
LPA (min/d)[b]	85 ± 14[c,e]	88 ± 13[c]	71 ± 14[d,e]	76 ± 15[d]	56 ± 16[e]	69 ± 18
MVPA (min/d)[b]	31 ± 9[c,e]	37 ± 11[c]	26 ± 9[d,e]	34 ± 11[d]	20 ± 10[e]	26 ± 11

PA = physical activity; CPM = counts per minute; LPA = light physical activity; MVPA = moderate-to-vigorous physical activity.
[a] 9 AM to 1 PM for six- and nine-year-olds, 9 AM to 2 PM for 15-year-olds.
[b] Mean ± standard deviation.
[c] Significantly different from nine- and 15-year-olds ($p < 0.001$).
[d] Significantly different from 15-year-olds ($p < 0.001$).
[e] Significantly different from boys in the same age group ($p \leq 0.045$).

association, only PPFs that had previously been observed to be used for play and/or sports activities during break-time were counted. In addition, PPFs that facilitated active play for several small groups of children at the same time were counted as more than one item (Nielsen et al., 2010, 2012; Taylor et al., 2011). This might have given a more detailed and realistic picture on PPF accessibility than in the present study, where we counted all individual play structures as one item. It is therefore possible that the associations between PPF provision, sedentary time and LPA found in the present study are underestimated. One could argue that a doubling of the sheer number of PPF (from ~22 to ~44 in an average Norwegian primary school) is neither realistic nor practical when we consider the relatively modest associations observed in the present study. However, investing in PPFs that promote PA for many children at the same time might both be realistic and practical. Further research is therefore needed to identify what sort of PPF increases PA-levels the most.

Although a few experimental studies have investigated the isolated effect of altering PPF availability (Ickes et al., 2013; Parrish et al., 2013; van Sluijs et al., 2007; Ridgers et al., 2010b), we are only aware of one such study with a long term follow-up. In this study, Ridgers et al. (2007) investigated the effect of redesigning the playground environment in elementary schools on MVPA and vigorous PA (VPA) during recess (Ridgers et al., 2007). Results demonstrated significant intervention effects after 6 weeks and 6 months (Ridgers et al., 2007), but at 12 months, the only significant intervention effect that remained was higher VPA during lunch recess (Ridgers et al., 2010b). This might indicate a novelty effect of the intervention and, furthermore, that regular changes in the outdoor playing environment might be necessary in future interventions to increase PA in the long term.

Using questionnaires to assess PA, Haug et al. (2010) investigated the association between characteristics of the outdoor school environment and PA in a nationally representative sample of Norwegian 13–15 year olds. They found that adolescents with access to the maximum number of play facilities had almost three times higher odds of being physically active during recess than adolescents attending schools not providing play facilities. Although comparability is limited because of the different methods used to assess both PA and play facilities, this is in contrast to our findings. We are not aware of studies that have investigated the association between objectively measured PA or sedentary time and PPF availability in adolescents.

Few cross-sectional studies have investigated the association between the size of SOPA and objectively measured PA in children, and the results are equivocal. Two studies conducted by Nielsen et al. (2010, 2012) support our findings of no association. On the other hand, five studies report positive associations between the size of SOPA and MVPA during recess (Sallis et al., 2001; Harten et al., 2008; Ridgers et al., 2010a; D'Haese et al., 2013; Escalante et al., 2012). Furthermore, interventional studies indicate a positive effect of increasing the size of SOPA per pupil on PA during recess (Loucaides et al., 2009; D'Haese et al., 2013; Harten et al., 2008). Although small sample sizes and short follow-up limit the generalizability of these studies, they contrast with our findings.

One possible reason for the differing results might be due to the actual size of SOPA. In the present study, and in the studies by Nielsen et al., the size of SOPA per pupil was much larger than in the other studies. In PANCS2, only four of the 60 participating primary schools provided < 15 m^2 of outdoor play space per pupil, while none of the 18 schools in the study by Nielsen et al. (2012) conducted on Danish children provided <77 m^2 per pupil. In comparison, none of the 11 participating schools in the two studies by Ridgers et al. (2010a) and D'Haese et al. (2013) provided >16.9 m^2 per pupil. It is therefore likely that smaller

Table 3
Permanent play facility provision and the size school's outdoor play area in schools participating in the Physical Activity Among Norwegian Children Study in 2011 (n = 99).

	6-year-olds	9-year-olds	15-year-olds
Permanent play facilities[a]	22.2 ± 7.5	21.7 ± 7.8	10.9 ± 7.1[b]
Per pupil[a]	0.095 ± 0.055	0.093 ± 0.058	0.037 ± 0.033[b]
SOPA (m^2)[a]	15,249 ± 7958	15,128 ± 8018	14,428 ± 7279
Per pupil (m^2)[a]	65.6 ± 45.2	62.9 ± 43.0	49.9 ± 35.7[b]

SOPA = school's outdoor play area.
[a] Mean ± standard deviation.
[b] Significantly different from 6- and 9-year-olds ($p < 0.001$).

Table 4
Associations between permanent play facility provision, physical activity and sedentary time among Norwegian children and adolescents in 2011 (n = 2588).[a]

	Age	n pupils (n schools)	B[b,c]	95% CI
Overall PA (CPM)	6	837 (55)	19.91	−26.09, 65.90
Sedentary (minutes)	6	837 (55)	−3.78*	−7.28, −0.28
LPA (minutes)	6	837 (55)	2.16**	0.53, 3.79
MVPA (minutes)	6	837 (55)	1.67	−0.55, 3.89
Overall PA (CPM)	9	1126 (55)	7.35	−36.65, 51.35
Sedentary (minutes)	9	1126 (55)	−1.92	−6.23, 2.39
LPA (minutes)	9	1126 (55)	1.93	−0.36, 4.22
MVPA (minutes)	9	1126 (55)	0.04	−2.52, 2.59
Overall PA (CPM)	15	625 (36)	−25.08	−94.74, 44.57
Sedentary (minutes)	15	625 (36)	0.17	−7.29, 7.64
LPA (minutes)	15	625 (55)	0.77	−4.08, 5.61
MVPA (minutes)	15	625 (36)	−0.90	−5.95, 4.14

PA = physical activity; CPM = counts per minute; LPA = light physical activity; MVPA = moderate-to-vigorous physical activity.
* $p = 0.034$.
** $p = 0.009$.
[a] Data on one or more of the covariates in the statistical models were missing for 452 of the 3040 participants that met the inclusion criteria, therefor the results from the analyses are based on a total of 2588 participants.
[b] Beta values represent daily change associated with increasing the number of permanent play facilities per pupil by 0.1.
[c] Analyses adjusted for: accelerometer wear time (except analyses of CPM); measurement month; socioeconomic status; the dummy variables “access to areas outside school property during recess”, “sectioning of the play area during recess”, “recess at different time points for different classes” and “allowed to spend recess indoors”.

Table 5
Associations between the size of school's outdoor play area, physical activity and sedentary time among Norwegian children and adolescents in 2011 ($n = 2588$)[a].

	Age	n pupils (n schools)	B[b,c]	95% CI
Overall PA (cpm)	6	837 (55)	3.43	−3.80, 10.67
Sedentary (minutes)	6	837 (55)	−0.01	−0.54, 0.52
LPA (minutes)	6	837 (55)	−0.02	−0.38, 0.33
MVPA (minutes)	6	837 (55)	0.03	−0.24, 0.29
Overall PA (minutes)	9	1126 (55)	2.40	−4.07, 8.88
Sedentary (minutes)	9	1126 (55)	0.08	−0.75, 0.59
LPA (minutes)	9	1126 (55)	0.06	−0.36, 0.47
MVPA (minutes)	9	1126 (55)	0.03	−0.32, 0.39
Overall PA (cpm)	15	625 (36)	−2.0	−3.39, 3.40
Sedentary (minutes)	15	625 (36)	−0.47	−1.26, 0.32
LPA (minutes)	15	625 (36)	0.86*	0.21, 1.50
MVPA (minutes)	15	625 (36)	−0.41**	−0.77, −0.05

PA = physical activity; CPM = counts per minute; LPA = light physical activity; MVPA = moderate-to-vigorous physical activity.
* $p = 0.009$.
** $p = 0.027$.
[a] Data on one or more of the covariates in the statistical models were missing for 452 of the 3040 participants that met the inclusion criteria, therefor the results from the analyses are based on a total of 2588 participants.
[b] Beta values represent daily change associated with increasing outdoor play area size by 10 m^2.
[c] Analysis adjusted for: accelerometer wear time (except analyses of CPM); measurement month; socioeconomic status; number of permanent play facilities; the dummy variables "access to areas outside school property during recess", "sectioning of the play area during recess", "recess at different time points for different classes" and "allowed to spend recess indoors".

outdoor play areas might inhibit the PA level of children, but that most Norwegian schools provide children with sufficient outdoor play space to be physically active. Explorative analyses of the third of schools ($n = 16$) providing the least play space per pupil in the present study (4–40 m^2) did however indicate a positive association between play space and MVPA among nine-year-olds (data not shown). Further research on a larger sample of schools with smaller outdoor play areas (e.g. <40m^2) could be useful for developing general recommendations on the minimum outdoor play space per pupil that should be provided with regard to PA.

Discrepancy in results between studies could also be due to differences in methods used to measure PA. In our study, and in the studies by Nielsen et al. (2010, 2012), PA was measured objectively and continuously for several days. The other studies measured PA levels during recess only (D'Haese et al., 2013; Escalante et al., 2012; Harten et al., 2008; Ridgers et al., 2010a; Sallis et al., 2001). Isolating the PA measurements to recess could be more sensitive and therefore enable the detection of smaller differences in PA. However, if children are aware of the PA-monitoring, either as consequence of being observed (Ridgers et al., 2010a; Sallis et al., 2001) or being equipped with a PA monitor just before recess (D'Haese et al., 2013; Escalante et al., 2012; Harten et al., 2008), they might alter their normal recess behavior (Dossegger et al., 2014). Thus, a Hawthorne effect cannot be excluded (McCambridge et al., 2014).

Although the size of SOPA was negatively associated with MVPA and positively associated with LPA among 15-year-olds, these associations were weak and likely not clinically meaningful. When we also take into consideration that only five of the 44 included lower secondary schools provided ≤20 m^2 of outdoor play area per pupil, we could expect that the size of SOPA does not seem to be a limiting factor for PA among the 15-year-olds.

4.1. Study limitations and strengths

A major strength of the present study is the large, nationally representative sample of children and adolescents. Another strength is the objective and continuous measure of PA over multiple days. Because of known difficulties with accurately recalling details about PA, especially among children (Sallis and Saelens, 2000), objective measurement with accelerometers is considered the best option in large scale studies (Westerterp, 2009). Lastly, the high number of participants from a large number of schools allowed us to include several covariates in the statistical models.

This study also has some important limitations. First, this is a cross-sectional study, and we can therefore not make inferences about cause and effect. Second, because several schools did not provide us with class schedules, we were not able to use isolated recess PA/sedentary time in the analyses, or to control for PE. However, we used analyses that partly account for nesting effects within schools, and we do not have any indications that recess or PE durations were not randomly distributed between schools. Third, we did not consider the use and quality of the PPFs. Therefore, it is unknown how many pupils actually used the different play facilities, or how much PA they could potentially generate. Fourth, because we used vertical accelerations of the hip to assess PA, it is likely that the intensity (energy expenditure) of PA involving substantial upper-body movements, such as climbing, was underestimated (Lee and Shiroma, 2013). Lastly, we do acknowledge that landscape features, such as areas with a naturalistic feel and areas with different surfaces, may influence the PA level of children (Anthamatten et al., 2014; Fjørtoft, 2004). Because of the risk of overfitting the regression models, we chose not to adjust for this. Additional explorative analyses using soft surface area, asphalt area or treetop-covered area as the dependent variable in the model did not change the observed results.

5. Conclusions

Our results indicate that increasing the sheer number of PPFs in SOPA may be beneficial to reduce sedentary time and increase time spent in LPA among six-year-olds, but not among nine- and 15-year-olds. In order to recommend cost-effective changes to SOPA, there is a need to identify what types of PPFs that increase PA-levels the most, especially in adolescents. The size of SOPA did not seem to be a limiting factor for PA in the present study. This may be explained by the large outdoor areas generally observed in Norwegian schools.

Conflicts of interest statement

The authors declare that there are no conflicts of interest.

Transparency document

The Transparency document associated with this article can be found, in online version.

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Paper IV

Cross-sectional and prospective associations between sleep, screen time, active school travel, sports/exercise participation and physical activity in children and adolescents

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Abstract

Background: The aim of this study was to investigate how sleep, screen time, active school travel and sport and/or exercise participation associates with moderate-to-vigorous physical activity (MVPA) in nationally representative samples of Norwegian 9- and 15-y-olds, and whether these four behaviors at age nine predict change in MVPA from age nine to 15 years.

Method: We pooled cross-sectional accelerometer and questionnaire data from 9- (n=2,366) and 15-y-olds (n=1,554) that participated in the first (2005/06) and second (2011/12) wave of the Physical Activity among Norwegian Children Study to investigate cross-sectional associations. To investigate prospective associations, we used data from a sub-sample that participated in both waves (at age nine and 15 years, n=517).

Results: Cross-sectional analyses indicated a modest, inverse association between screen time and MVPA among 9- (-2.2 min/d (95% CI: -3.1, -1.3)) and 15-y-olds (-1.7 min/d (95% CI: -2.7, -0.8)). Compared to their peers with 0-5 min/d of active travel to school, 9- and 15-y-olds with ≥16 min/d accumulated 7.2 (95% CI: 4.0, 10.4) and 9.0 (95% CI: 3.8, 14.1) more min/d of MVPA, respectively. Nine-y-old boys and 15-y-olds reporting ≥8 hours/week of sports and/or exercise participation accumulated 14.7 (95% CI: 8.2, 21.3) and 17.9 (95% CI: 14.0, 21.8) more min/d of MVPA, respectively, than those reporting ≤2 hours/week. We found no cross-sectional association between sleep duration and MVPA in either age group. None of the four behaviors predicted change in MVPA from age nine to 15 years ($p \geq 0.102$).

Conclusion: Active travel to school and sport/exercise participation may be important targets for future interventions aimed at increasing MVPA in children and adolescents. However, future studies are needed to determine causality.

Introduction

Research conducted over the last two decades has identified a multitude of factors potentially important for the promotion of PA in children and adolescents [1]. This knowledge has aided development of interventions designed to increase young people's PA, but unfortunately, many such interventions have only had limited or moderate success thus far [2-4]. Therefore, there is undeniably a continued need to increase our knowledge about modifiable factors potentially influencing PA in children and adolescents.

Some previous research has shown sleep duration [5, 6], screen time [7-10], active school travel [11-15] and sport/exercise participation [16, 17] to be associated with PA in children and adolescents. The observed associations between the two former behaviors and PA has recently led some authorities to include recommended levels of sleep and screen time to their PA guidelines for children [18]. However, the links between all these four potentially modifiable behaviors and PA stem predominantly from cross-sectional studies, limiting causal inference.

Prospective studies examining determinants of PA have usually modelled these associations as change in the exposure with change in the outcome [17, 19-22], which does not determine the direction of association [23]. As an example, when an association between maintenance/adoption of organized sport participation associates with a beneficial change in PA, it is impossible to rule out that children who are more active and fit choose to continue or adopt organized sport participation [17]. Therefore, one cannot infer that organized sport participation predicts a higher PA level at a later time point.

In the Physical Activity among Norwegian Children Study (PANCS), we have collected data on PA, sleep duration, screen time, active school travel and sport/exercise participation in randomly selected, nationally representative samples of 9- and 15-y-olds in 2005-06 and

2011-12. In addition, a sub-sample of the participants were followed prospectively from age nine (2005-06) to 15 (2011-12) years. To inform future public health strategies and interventions for children and adolescents, we examined the cross-sectional and prospective associations between sleep duration, screen time, active school travel, sport/exercise participation and PA.

Methods

Participants

PANCS is designed to monitor secular and longitudinal changes in PA in nationally representative samples of children and adolescents [24], and serves as the national PA surveillance system in Norway. The current study used pooled cross-sectional data from the first and second wave of PANCS (PANCS1 and PANCS2), and data collected from a sub-sample of participants followed prospectively from age ~9 years in PANCS1 to age ~15 years in PANCS2.

In PANCS1 (2005/06), we recruited 9- and 15-y-olds using a cluster sampling technique with schools as the primary unit. All fourth and tenth graders from schools that agreed to take part in the study were invited. In PANCS2 (2011/12), we recruited a new nationally representative sample of 9-y-olds using the same sampling technique as in PANCS1, whereas 15-y-olds were recruited either individually based on previous participation in PANCS1 (prospective sample) or from a random sample of lower secondary schools (cross-sectional sample).

Anthropometrics

We measured height to 0.1 cm using a wall-mounted measuring tape, weight to 0.1 kg using Seca 770 and 877 scales (SECA GmbH, Hamburg, Germany) and calculated body mass index (BMI) using the standard formula (kg/m^2). In PANCS1, the participants wore underwear during anthropometric measurements, whereas in PANCS2, they wore gym shorts and a t-shirt. Therefore, we subtracted 0.3 kg from the PANCS2 participants' measured weight.

Socioeconomic status

We categorized the participants into three socioeconomic status (SES) groups based on the parent with the highest education level. The parents self-reported this information in PANCS1, whereas Statistics Norway provided the information in PANCS2. Categories were coded "low", (primary school or lower secondary school), "middle" (high school (vocational or general studies) and "high" (University College or University).

Physical activity

We assessed PA using ActiGraph accelerometers (ActiGraph, LLC, Pensacola, Florida, USA). In PANCS1, we used the CSA 7164 model. In PANCS2, we used the GT1M and GT3X+ models. We used the RIU (K64, Computer Science & Application Inc, Shalimar, FL) and ActiLife software (ActiGraph, LLC, Pensacola, Florida, USA) to initialize and download the accelerometers PANCS1 and PANCS2, respectively, and KineSoft (v3.3.76; KineSoft, Loughborough, United Kingdom) for further processing of the accelerometer data.

We programmed the accelerometers to start recording at 06:00 on the day after the participants received them, and to sample activity counts in 10 s epochs. During school visits, we instructed the participants to wear the monitor on their right hip for four (PANCS1) and seven (PANCS2) consecutive days, and to remove the monitor for sleep and water based activities only. The different number of monitoring days is due to the limited storage capacity of the CSA 7164 model compared to the two newer models.

After exclusion of data recorded on weekend days, data recorded from 00:00-06:00 and intervals of ≥20 consecutive minutes with no activity counts recorded, we deemed all files with ≥2 weekdays consisting of ≥480 minutes of activity count recordings eligible for analysis.

In order to investigate average time spent in MVPA on weekdays, we applied a cut-point of ≥2000 counts·min^{-1} (CPM) scaled to match the 10 s epochs used, and divided all time spent in MVPA by the number of valid assessment days. This MVPA cut-point was developed for the European Youth Heart Study (EYHS) [25], is based on several validation studies and equivalent to a walking speed of >4 km/h in children and adolescents [26].

Sleep

Participants reported when they usually got out of bed and went to bed on schooldays. A detailed description of the questionnaire is provided as online supporting information (Table S1). To estimate sleep duration, we subtracted and added 0.5 hours to the lower ("Before 06:30/20:00) and upper ("After 08:00/24:00") categories, respectively, and used the halfway point within remaining categories (e.g. "06:30-07:00" recoded 06:45). We then applied the following algorithm to approximate sleep duration on a numeric, continuous scale: *((24:00 – "bed time") + (00:00 + "out of bed")) = sleep duration*. This yielded 12 and 11 different sleep durations ranging from 5.75 to 12.25 hours/night in 9- and 15-y-olds, respectively.

Screen time

We computed screen time by combining information from three questions in the questionnaire. The participants indicated how many hours they usually watched TV before and after school, and how many hours they usually spent in front of a computer or with a videogame on schooldays (Table S1). To approximate total screen time on a numeric scale, we used the midway point in the second lowest to the second highest categories and added 0.5 hour to the highest categories. We then summed TV time before school, TV time after school and PC/videogame time on weekdays. This yielded 17 and 18 different screen times ranging from zero to 9.5 hours/day in 9-y-olds and 15-y-olds, respectively.

Active school travel

Participants reported their usual travel mode and duration of travel to school. (Table S1). These data were stratified into three groups; 0) No active travel or < 5 min of active travel; 1) between 6 and 15 min of active travel, and; 2) ≥16 minutes of active travel.

Sports/exercise participation

Participants indicated how many hours per week outside of school they did sports or exercised (Table S1). Because of the limited number of participants in each category, we combined the lowest two categories, the middle two categories, and the upper two categories. The participants where then grouped accordingly.

Analysis

We performed all statistical analyses using Stata 13.1 (StataCorp. 2013. Stata Statistical Software: TX: StataCorp LP.). Cross-sectional differences at baseline between the analytical sample and those lost to follow-up (prospective study sample) were analyzed using simple linear regression (continuous dependent variables) and simple ordered logistic regression (ordinal dependent variables).

Cross-sectional associations between MVPA (dependent variables) and the independent variables (sleep, screen time, school travel mode and sports/exercise) at age nine and 15 years were analyzed using linear regression, adjusted for accelerometer wear time, sex, BMI, SES and minutes of daylight.

Prospective associations between changes in MVPA from baseline to follow-up and predictor variables (baseline sleep, baseline screen time, baseline school travel mode and baseline sports/exercise), were analyzed using linear regression adjusted for accelerometer wear time, baseline MVPA, sex, baseline BMI, baseline SES and change in minutes of daylight between baseline and follow-up.

Because of the aforementioned cluster sampling, we used Statas *xtreg, re* command (generalized least-square, random effects) with school declared (*xtset*) as the panel, and incorporated school as a cluster variable in both cross-sectional and prospective analyses using the *vce cluster* option to obtain robust variance estimations. In the prospective analyses, we used school at baseline as the cluster variable. We excluded participants with missing values for any of the variables in the statistical models thru listwise deletion.

Since there were more than five sleep and screen time durations, reasonably large sample sizes and the sleep and screen time data were normally distributed, we chose to treat sleep and screen time as a continuous variable in all the analyses [27].

Lastly, we fitted interaction terms in initial analyses to assess whether sex modified associations. In analyses where the interaction term had a p-value less than 0.1, we stratified the analyses by sex to investigate to what extent sex was a modifier.

Results

Cross-sectional associations

In PANCS1, we invited 1,470 9-y-olds and 1,348 15-y-olds to participate, of which 1,306 (89%) and 993 (74%) agreed to take part in the study. In PANCS2, we invited 1,945 9-y-olds and 1,759 15-y-olds, of which 1,421 (73%) and 1,106 (63%) agreed to participate. Combined, this yields participation rates of 80% and 68% for the 9- and 15-y-old study samples, respectively. A total of 2,366 9-y-olds and 1,554 15-y-olds provided ≥2 valid weekdays of accelerometer data. Table 1 displays descriptive characteristics of the analytical sample.

Sleep duration was not associated with MVPA in either age group ($p \geq 0.274$, table 2, figure 1A). This association was unchanged in sensitivity analysis where we substituted the continuous sleep variable for a dichotomous variable based on suggested sleep recommendation attainment (9-11 hrs/night in 9-y-olds and 8-10 hrs/night in 15-y-olds, data not shown). 82.6% and 53.7% of 9- and 15-y-old participants reported sleeping the recommended minimum or more, respectively.

Table 1: Background characteristics of the cross-sectional and prospective study samples (mean (SD) unless otherwise specified)

	Cross-sectional samples				**Prospective sample**			
	9-y-olds	**n**	**15-y-olds**	**n**	**Baseline**	**n**	**Follow-up**	**n**
Girls	49.4%		51.0%		48.9%		48.9%	
Age (years)	9.6 (0.4)	2366	15.3 (0.6)	1554	9.6 (0.4)	517	15.2 (0.7)	517
Height (cm)	138.7 (6.6)	2342	169.6 (8.3)	1490	139.1 (6.4)	515	169.8 (8.4)	477
Weight (kg)	33.9 (6.8)	2343	60.7 (11.4)	1474	33.4 (6.3)	515	59.8 (10.5)	469
BMI ($kg \cdot m^{-2}$)	17.5 (2.6)	2340	21.0 (3.3)	1473	17.2 (2.4)	515	20.7 (3.0)	469
SES								
Low	6.8%	153	5.9%	82	5.8%	29	5.8%	29
Middle	37.7%	843	38.8%	543	35.5%	179	35.5%	179
High	55.5%	1243	55.4%	776	58.7%	296	58.7%	296
MVPA (min/d)	92.1 (30.6)	2366	68.6 (26.3)	1554	98.2 (33.3)	517	69.5 (25.6)	517
Sleep (hrs/d)	9.7 (0.8)	2102	8.1 (0.9)	1165	10.3 (0.6)	478	7.5 (0.7)	382
Screen time (hrs/d)	2.6 (1.3)	2081	3.9 (1.6)	1209	2.4 (1.3)	476	3.9 (1.6)	399
Active transport								
0-5 min/d	43.7%	926	52.3%	652	38.6%	188	48.9%	204
6-15 min/d	35.8%	757	36.1%	450	40.5%	197	36.7%	153
≥16 min/d	20.5%	434	11.6%	1247	20.9%	102	14.4%	60
Sports/exercise								
≤2 hrs/week	36.1%	762	30.2%	373	30.8%	150	28.6%	117
3-7 hrs/week	53.1%	1119	46.8%	577	56.1%	273	43.8%	179
≥8 hrs/week	10.8%	228	23.0%	284	13.1%	64	27.6%	113

SES, socioeconomic status; MVPA, moderate-to-vigorous physical activity; hrs/d, hours per day; min/d, minutes per day; hrs/week, hours per week

In 9- and 15-y-olds, we found inverse associations between screen time and MVPA (figure 1B), translating to 2.2 and 1.7 min/d less MVPA for each additional hour of screen time, respectively (table 2). Dichotomizing screen time based on suggested recommended levels revealed that 9-y-olds spending >2 hrs/d in front of a screen accumulated 4.3 min/d (95% CI: 1.9, 6.8) less MVPA than 9-y-olds spending ≤2 hrs/d. Among 15-y-olds, sex modified this association (p=0.014), and a difference between groups was only evident among boys (9.9 min/d (95% CI: 3.8, 16.1)). The proportions of 9- and 15-y-olds spending >2 hrs/d in front of a screen were 53.5% and 81.3%, respectively.

Table 2: Associations from cross-sectional analyses[1]

	9-y-olds MVPA (b (95% CI))	n	15-y-olds MVPA (b (95% CI))	n
Sleep	0.3 (-1.5, 2.2)	2053	1.3 (-1.0, 3.6)	1120
Screen time	-2.2 (-3.1, -1.3)**	2033	-1.7 (-2.7, -0.8)**	1162
Active transport				
≤5 min/d	ref.	900	ref.	619
6-15 min/d	3.6 (0.9, 6.3)**	742	3.3 (0.4, 6.2)*	440
≥16 min/d	7.2 (4.0, 10.4)** ♀♂	424	9.0 (3.8, 14.1)**	137
Sports/exercise				
≤2 hrs/week	ref.	736	ref.	350
3-7 hrs/week	2.2 (-0.1, 4.5)	1098	7.6 (4.3, 10.8)**	555
≥8 hrs/week	9.2 (4.7, 13.7)** ♀♂	225	17.9 (14.0, 21.8)**	279

[1]Adjusted for accelerometer wear time, sex, BMI, SES and daylight

MVPA, moderate-to-vigorous physical activity; b (95% CI), beta coefficient (95% confidence interval); min/d, minutes per day; hrs/week, hours per week; ♀♂, association modified by sex (p≤0.036); *, p≤0.027; **, p≤0.009; ref, reference group

In both 9- and 15-y-olds, active school travel was positively associated with MVPA (p≤0.027). Among 9-y-olds, sex modified the association (figure 1C), and when comparing those with the lowest (0-5 min/d) and highest (≥16 min/d) quantity of active school travel, the differences were 10.5 min/d of MVPA (95% CI: 6.8, 14.3) in girls and 5.0 min/d of MVPA (95% CI: 0.4, 9.7) in boys. Further, when comparing 9-y-olds with the lowest amount of active school travel to those with 6-15 min/d, the difference in MVPA was significant in girls (4.6 min/d, 95% CI: 1.5, 7.8), but not boys (p=0.253). Among 15-y-olds, the association between active school travel and MVPA was similar in girls and boys and appeared to be dose-dependent (table 2, figure 1C).

Among 9-y-olds, sex modified the association between sport/exercise participation and MVPA (figure 1D, p<0.01). Boys who reported doing ≥8 hours/week of sports or exercise accumulated 14.7 min/d (95% CI: 8.2, 21.3) more MVPA than boys reporting ≤2 hours/week. No difference in MVPA was observed between girls in these two groups (p=0.571). Sex-stratified analyses also revealed that boys, but not girls (p=0.508), in the 3-7 hours/week group accumulated more MVPA than their peers in the ≤2 hours/week group (4.5 min/d (95% CI: 0.9, 8.2). Among 15-y-olds, both the 3-7 and ≥8 hours/week groups accumulated significantly more MVPA than the ≤2 hours/week group ($p<0.001$). Sex did not modify these associations, and the associations appeared to be dose dependent (table 2, figure 1D).

Prospective associations

In PANCS2, we were able to track and invite 1,119 of the 1,306 that participated in PANCS1 at age 9 years. Of these, 731 (65%) agreed to take part in PANCS2, of which 517 provided ≥2 valid weekdays of accelerometer data in both PANCS1 and PANCS2. Table 1 displays descriptive characteristics of the prospective study sample at baseline and follow-up.

Compared to those lost to follow-up, the prospective study sample had a lower BMI, slept more, reported less screen time and reported more time doing sports or exercising at baseline ($p\leq0.022$, online supporting information, Table S2).

Table 3: Associations from prospective analyses

	MVPA (b (95% CI)) [2]	**n**
Sleep	1.3 (-2.9, 5.5)	466
Screen time	-1.6 (-3.5, 0.3)	464
Active transport		
≤5 min/d	ref.	186
6-15 min/d	2.2 (-3.0, 7.4)	191
≥16 min/d	-2.0 (-9.2, 5.2)	98
Sports/exercise		
≤2 hrs/week	ref.	145
3-7 hrs/week	2.0 (-2.5, 6.6)	269
≥8 hrs/week	5.1 (-1.6, 11.8)	61

[1] Adjusted for accelerometer wear time, baseline MVPA, sex, baseline BMI, baseline SES and change in daylight from baseline to follow-up.
[2] Beta values: impact of baseline sleep, screen time, active transport and sports/exercise on change in MVPA from baseline to follow-up.
b (95% CI), beta coefficient (95% confidence interval); min/d, minutes per day; ref., reference group; MVPA, moderate-to-vigorous physical activity; hrs/week, hours per week.

The mean (SD) interval between baseline and follow-up assessments was 5.6 (0.5) years, during which MVPA decreased by an average of almost 30 min/d (table 1). Table 3 displays the results from the prospective analyses. Sleep duration, screen time, active school travel and time spent doing sports or exercise at age 9 years were not associated with change in MVPA from age 9 to 15 ($p \geq 0.102$). Dichotomizing sleep duration and screen time at baseline based on suggested recommendations did not change the results ($p \geq 0.163$).

Discussion

Our cross-sectional results suggested that screen time, active school travel and sports/exercise participation may influence habitual MVPA in both 9- and 15-y-olds. In contrast, we did not observe any association between these behaviors and objectively measured MVPA in prospective analyses.

Sleep: Insufficient sleep is associated with several negative physical and mental health outcomes [28]. Thus, it is recommended that children (ages 6-13 years) and adolescents (ages 14–17 years) sleep 9–11 h/night and 8–10 h/night, respectively [29]. One hypothesis is that sufficient sleep facilitates a more physically active lifestyle, which has well-established health benefits in young people [30, 31]. If true, the associations between sleep and health outcomes might exist in synergy with associations between PA and health outcomes [32]. However, our results are in line with some [6, 19, 33-37] but not all [38, 39] previous studies and do not confirm the hypothesis that short sleep duration negatively affects MVPA. Further, in one of very few experimental studies investigating the effect of altering sleep duration on habitual MVPA [40], Hart et al. (2016) found no difference in objectively assessed MVPA between one week of decreased sleep (-1.5 hrs./d) and one week of increased sleep (+1.5 hrs./d) in 8-11 year-old children [34].

Screen time: The cross-sectional associations we observed corroborate a systematic review and meta-analysis conducted by Pearson et al. (2014) finding an overall small inverse association between screen time and PA [41]. Previous studies have also indicated that screen time during childhood is a poor predictor of objectively assessed PA [42]. In our cross-sectional study samples, a one SD higher screen time was associated with <3 min/d lower

MVPA suggesting a weak and possibly not clinically meaningful association. Considering that a meta-analysis of 33 interventions aimed at reducing screen time in children and adolescents only showed a small overall effect [43], the potential of screen time reduction as a component in interventions aiming to increase MVPA seems limited. Nevertheless, studies are indicative of an indirect relationship between TV viewing and cardiovascular disease risk in young people [44-46]. Therefore, efforts made to limit TV viewing may have important public health implications, irrespective of its weak association with MVPA.

Active school travel: Larouche et al. (2014) systematically reviewed 28 studies examining the association between active school travel and accelerometer assessed PA and found that the majority (N=22) reported a positive association [13]. An interesting observation in our study is the stronger association in 9-y-old girls than in boys. Cooper et al. (2006) reported a similar observation in Danish 9-y-olds [47], but several studies have reported an association in boys only, including a study in Swedish and Estonian 9- and 15-y-olds [48]. This might indicate cultural differences, even between neighboring countries, and that facilitation and promotion of active school travel could be a valuable component in future interventions aiming to increase MVPA in young girls in Norway.

The seemingly dose-dependent relationship between active school travel and MVPA among 9-y-old girls and 15-y-olds observed in this study is similar to associations reported between active school travel distance and MVPA by others [49, 50]. Future studies separating walking and cycling as active behaviors are warranted to aid our understanding about the potential impact of these two behaviors during active transport on MVPA in young people.

Active travel can be thought of as part of a young person's PA skillset. Therefore, we can hypothesize that active travel during childhood may convey self-efficacy regarding PA capacity, potentially lowering the barriers perceived towards PA later in life. However, our results does not indicate that active school travel during childhood is a predictor of MVPA during adolescents. Because accelerometers underestimate MVPA during cycling [51], and the proportion of participants in the prospective study sample who cycled to school increased from 6.2% to 17.0% between baseline and follow-up, it is possible that adoption of a change of mode of transportation between age nine and 15 years may have masked a potential prospective associations in our study.

Sports/exercise participation: Our results corroborate those from a systematic review suggesting a positive association between sport participation and MVPA [52]. We consider the strength of the associations we observed comparable to those reported by Hebert et al. (2015), which found leisure-time sport participation to associate with 5-20 min/d more MVPA, depending on the type of sport and frequency of participation [16]. However, we did not observe any association between sports/exercise participation and MVPA in 9-y-old girls. We can only speculate as to why girls and boys that report doing the same amount of sports/exercise have different levels of habitual MVPA. One possibility is that girls and boys accumulate different levels of MVPA during the same sports and/or exercise activities. There is however very little data available regarding activity levels of girls and boys during specific activities outside of school to support this. Although accelerometers do not have the ability to distinguish between PA types under free-living conditions, merging minute-by-minute data from accelerometers with activity logs can potentially facilitate investigation of gender differences in MVPA during specific activities in future studies. It is also possible that the 9-y-old girls and boys participated in different sports and/or exercise activities that yield different levels of MVPA.

A compensatory mechanism has been suggested when PA is high in one domain (e.g. during sport/exercise) [53], which might result in similar daily levels of MVPA among girls with different levels of sports/exercise participation. However, current research testing this "activity-stat" hypothesis is inconclusive, and does not suggest a sex difference [53].

Similar to active travel, we can hypothesize that participation in sports and exercise during childhood determines higher levels of PA later in life through an increased self-efficacy regarding PA capacity. However, sports/exercise participation during childhood was not associated with change in MVPA between age nine and 15 years in our study sample. This is supported by Brooke et al. (2014), who found no association between variety and frequency of sports and exercise activities at age 10 and MVPA at age 14, and Basterfield et al. (2014), who found no association between minutes per week of sports club participation at age 9 and MVPA at age 12 [54, 55]. Taken together, a general promotion of sports and/or exercise participation during childhood does not seem to protect against the well-established MVPA decline from childhood to adolescence [24]. However, future studies investigating the prospective association between specific types of sports and exercises and objectively assessed MVPA are warranted.

Strengths and limitations

A major strength of this study is the large, population-based samples of children and adolescents and the high participation rates. Another strength is the objective measure of habitual MVPA, reducing the risk of biases associated with self-report [56]. Furthermore, 90% of the participants wore the monitor for an average >720 min/d, indicating that the vast majority awake time was monitored. In addition, we adjusted the regression models for a number of covariates reducing the risk of confounding and we explored interactions with sex.

However, our results should be interpreted with the following limitations in mind. Although the attrition rate in the prospective study sample is comparable to similar studies, the differences detected in the lost to follow-up analyses indicated selection bias. Although generalizability is not required to detect associations, this makes it plausible that the results are not fully generalizable to a larger population of nine and 15-year old Norwegians.

Further, the absolute validity of the questions used to measure the exposure variables is unknown. Even if other studies have used similar methods and we consider the face validity reasonable, this is a limitation. In addition, random measurement error is inherent when self-report is used to assess the quantity of behaviors in young people. This may lead to regression dilution bias [57], increasing the risk of type 2 errors.

Also of note is that we did not assess other aspects of the exposure variables that may be associated with MVPA. For example, we did not investigate whether sleep quality, different screen behaviors, different active travel modes to/from other destinations than school and participation in specific types of sport and exercise associates with MVPA. Because three of the four behaviors were specific to weekdays, we also chose to exclude weekend MVPA to ease the interpretation of the findings. However, we cannot rule out that the behaviors are associated with weekend MVPA also.

Lastly, hip-worn accelerometers under-estimate non-ambulatory PA such as cycling [51], which will likely attenuate associations between active school travel and MVPA. The same is also probable for associations between the three other behaviors and MVPA in participants who were avid cyclists.

Conclusion

In conclusion, this study adds to the growing body of evidence linking active school travel and participation in sport and exercise to habitual MVPA. In Norwegian children and adolescents, MVPA on weekdays does not however seem associated with sleep duration, and only weekly associated with screen time. Although we did not observe any prospective associations between any of the four behaviors investigated and MVPA, we believe our cross-sectional findings should encourage more studies to investigate whether altering active school travel and participation in sports and/or exercise impacts habitual MVPA using a randomized study design. Given the highly complex nature of the decline in MVPA from childhood to adolescence, we also encourage future observational studies to investigate prospective associations between additional aspects of these behaviors and MVPA.

Abbreviations

PA: physical activity; MVPA: moderate-to-vigorous physical activity; 6-/9-/15-y-old(s): 6-/9-/15-year-old(s); PANCS: the Physical Activity among Norwegian Children Study; BMI: body mass index; SES: socioeconomic status.

Declarations

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Ethics approval and consent to participate

The Regional Committee for Medical and Health Research Ethics approved PANCS1 (rek-sorost@medisin.uio.no), and the Norwegian Centre for Research Data (nsd@nsd.no) approved both studies. We obtained written informed consents from all participants and their primary guardians before the start of both data collections.

Consent for publication

Not applicable.

Availability of data and material

Please contact author for data requests.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Conception and design: S.A.A., L.B.A. and E.K.; data acquisition: E.K., B.H.H. and J.S.J.; data analysis and interpretation: K.E.D., S.A.A., E.K., B.H.H, J.S.J, U.E and L.B.A; drafting the manuscript: K.E.D.; critical revision for intellectual content: U.E. and L.B.A.; study supervision: S.A.A. All authors read and approved the final manuscript.

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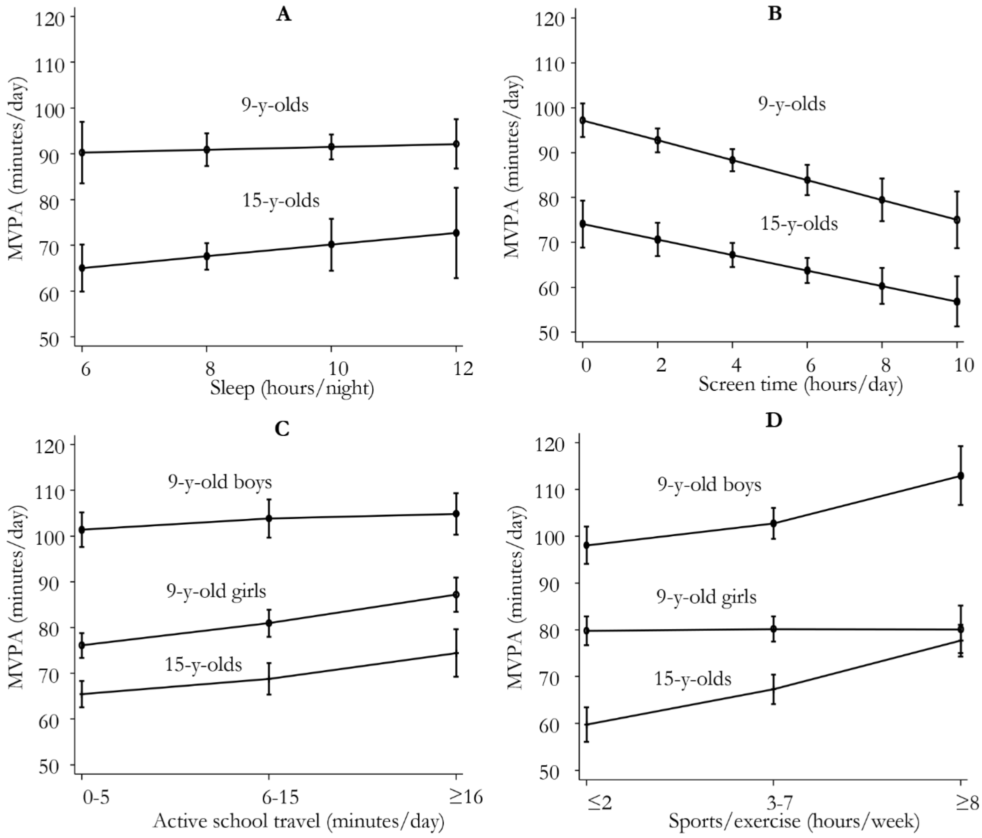

Figure 1: Cross-sectional associations between MVPA, sleep (A), screen-time (B), active school travel (C), sports/exercise participation (D). Mean values (95% CI) adjusted for accelerometer wear time, sex, body mass index (BMI), socioeconomic status (SES) and daylight. Nine-year-olds stratified by sex in C and D because of sex*active school travel (p=0.006) and sex*sports/exercise (p<0.001) interactions. MVPA, moderate-to-vigorous physical activity.

Table S1: Questions and possible answers from the questionnaire used to asses sleep duration, screen time, active school travel and sports/exercise participation)

Sleep duration	
When to you usually get out of bed on schooldays?	□ Before 06:30, □ Between 06:30 and 07:00, □ Between 07:00 and 07:30, □ Between 07:30 and 08:00, □ After 08:00[1]
When do you usually go to bed on schooldays?	□ Before 20:00, □ Between 20:00 and 21:00, □ Between 21:00 and 22:00, □ Between 22:00 and 23:00, □ Between 23:00 and 24:00, □ After 24:00[2]
Screen time	
How many hours do you usually watch TV before school?	□ None, □ Less than 1 hour, □ Between 1 and 2 hours, □ More than 2 hours
How many hours do you usually watch TV after school?	□ None, □ Less than 1 hour, □ Between 1 and 2 hours, □ Between 2 and 3 hours, □ Between 3 and 4 hours, □ More than 4 hours[3]
How many hours do you usually spend on a PC (to play games or surf the internet) or with a videogame (PlayStation, X-box or similar) on a weekday?	□ None, □ Less than 1 hour, □ Between 1 and 2 hours, □ Between 2 and 3 hours, □ Between 3 and 4 hours, □ More than 4 hours[4]
Active transport	
How do you usually get to school this time of year?[5]	□ By car or motorcycle, □ By bus, tram, metro or train, □ Cycle, □ Walk
How long does it usually take you to get to school?	□ Less than 5 minutes, □ 6-15 minutes □ 16 to 30 minutes, □ 31 minutes to 1 hour, □ More than 1 hour
Sports/exercise	
Outside of school: How many hours per week do you do sports/exercise that makes you breathe hard or sweat?	□ 0 hours, □ 1-2 hours, □ 3-4 hours, □ 5-7 hours, □ 8-10 hours, □ 11 hours or more

[1] In PANCS1, the highest category was "after 07:30"
[2] In PANCS1, the highest category was "after 22:00"
[3] In PANCS1, the highest category was "more than 3 hours"
[4] In PANCS1, the highest category was "more than 3 hours"
[5] "this time of year" was not specified in PANCS1

Table S2: Results from loss to follow-up analyses

	Study sample	n	Lost to follow-up	n
Age (years)	9.63 (0.38)	517	9.61 (0.39)	785
BMI ($kg \cdot m^{-2}$)	17.17 (2.40)*	515	17.55 (2.70)	768
Overweight (%)[2]	14.17*	515	20.83	768
Obese (%)[2]	2.72*	515	4.95	768
SES (%)		474		690
Low	6.54		8.55	
Middle	38.40		37.83	
High	55.06		53.62	
MVPA (min/d)	97.79 (34.08)	517	95.29 (34.79)	651
Sleep (hrs./d)	10.33 (0.56)*	478	10.25 (0.60)	704
Screen time (hrs./d)	2.43 (1.33)*	476	2.67 (1.45)	696
TV time (hrs./d)	1.49 (0.88)*	479	1.61 (0.99)	698
Computer time (hrs./d)	0.93 (0.80)*	480	1.07 (0.87)	706
Active transport (%)		487		705
0-5 min/d	38.60		41.56	
6-15 min/d	40.45		38.16	
≥16 min/d	20.94		20.28	
Sports/training (%)		487		698
≤2 hrs./week	30.80		37.68	
3-7 hrs./week	56.06*		50.72	
≥8 hrs./week	13.14*		11.60	

* Significantly different from those lost to follow-up ($p \leq 0.050$)

Appendices

Appendix 1:

Selection of studies that have assessed physical activity in more than 1000 children and/or adolescents using ActiGraph accelerometers.

Selected studies in which physical activity has been assessed using ActiGraph [A] accelerometers in more than 1000 participants.

Study [B]	Country	n	Years	Age
1) ALSPAC [1]	UK (England)	6,407	'03-'07	10-15
2) CLAN [2]	Australia	1,127	'01-'06	4-18
3) EYHS [3]	Denmark	1,267	'97-'04	8-18
4) HEAPS [4]	Australia	1,268	'02-'06	4-15
5) NHANES [5]	USA	4,201	'03-'14	6-18
6) PEACH [6]	UK (England)	1,178	'06-'09	9-12
7) EYHS [7]	Portugal (Madeira)	1,070	'99-'08	8-17
8) Project TAAG [8]	USA	4,308	'03-'06	10-16
9) SPEEDY [9]	UK (England)	1,875	'07	9-11
10) IDEFICS [10]	Multinational [10]	7,684	'07-'11	2-11
11) HELENA [11]	Multinational [11]	2,200	'06-'08	13-17
12) ISCOLE [12]	Multinational [12]	6,539	'11-'13	9-11
13) Ballabeina [13]	Switzerland	1,052	'08-'09	10-15
14) CHASE [14]	UK (England)	2,071	'06-'07	9-10
15) "PPPASPA" [15]	Portugal	2,714	'08-'09	10-18
16) B-ProAct1v [16]	UK	1,267	'12-'13	5-6
17) SPACE [17]	Denmark	1,348	'10	11-13
18) PANCS [18]	Norway	5,152	'05-'12	6-15
19) MCS [19]	UK	6,497	'08-'09	7-8

[A] Studies [2, 3, 4] and [8] used model 7164, studies [6, 9, 11, 13, 14, 15] and [19] used model GT1M, studies [12, 16] and [17] used model GT3X, studies [1] and [7] used models 7164 and GT1M, study [5] used models 7164 and GT3X, study [18] used models 7164, GT1M and GT3X, and study [10] used model GT1M and "Actitrainer".
[B] Studies 1-9 and 13 are among the studies providing data to ICAD [20].
[1] Avon Longitudinal Study of Parents and Children. [2] Children Living in Active Neighborhoods. [3] Denmark European Youth Heart Study. [4] Healthy Eating and Play Study. [5] National Health and Nutrition Examination Survey. [6] Personal and Environmental Associations with Children's Health. [7] Portugal European Youth Heart Study. [8] Project Trial of Activity for Adolescent Girls. [9] Sport, Physical activity and Eating behavior: Environmental Determinants in Young people.[10] Identification and prevention of dietary and lifestyle-induced health effects in children and infants (Sweden, Germany, Hungary, Italy, Cyprus, Spain, Belgium and Estonia). [11] The Healthy Lifestyle in Europe by Nutrition in Adolescence (Athens and Heraklion in Greece, Dortmund in Germany, Ghent in Belgium, Lille in France, Pécs in Hungary, Rome in Italy, Stockholm in Sweden, Vienna in Austria, and Zaragoza in Spain). [12] The International Study of Childhood Obesity, Lifestyle and the Environment (Australia, Brazil, Canada, China, Colombia, Finland, India, Kenya, Portugal, South Africa, United Kingdom, and the United State).[13] Influence of a Lifestyle Intervention in Preschool Children on Physiological and Psychological Parameters. [14] The Child Heart and Health Study in England. [15] The Prevalence of the Portuguese Population Attaining Sufficient Physical Activity study. [16] B-ProAct1v, Study to Evaluate the Impact of the "PROactive Telecoaching Program" on Physical Activity in Patients With COPD. [17] School site, Play Spot, Active transport, Club fitness and Environment study.[18] The Physical Activity Among Norwegian Children Study (the study this thesis builds upon).[19] The UK Millennium Cohort Study.

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Appendix 2:

Approval letters from the Regional Committees for Medical Research Ethics and the Norwegian Social Science Data Services.

UNIVERSITETET I OSLO

DET MEDISINSKE FAKULTET

Professor Dr.med Lars Bo Andersen
Norges idrettshøgskole

Regional komité for medisinsk forskningsetikk
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Nettadresse: www.etikkom.no

Dato: 30.11.04
Deres ref.:
Vår ref.: S-04305

Kost, aktivitetsvaner og helse blant barn og unge i Norge

Komiteen behandlet prosjektet i sitt møte torsdag 18. november 2004.

Komiteen har følgende merknader til prosjektet:

1. Hvordan følges eventuelle patologiske verdier på blodprøvene opp.

2. Komiteen forutsetter at undersøkelsen gjennomføres slik at den enkeltes integritet og privatliv ivaretas.

Komiteen har følgende merknader til søknad om opprettelse av forskningsbiobank:

1. Pkt 2: Stemmer det at prosjektleder er databehandlingsansvarlig, dette er vanligvis institusjonens øverste leder.

2. Data i studien er avidentifisert, ikke anonymisert, da det eksisterer en nøkkel som prosjektleder har tilgang til.

Komiteen har følgende merknader til informasjonsskriv og samtykkeerklæring:

1. Det må utarbeides egen informasjon til barna, evt. må overskriften på informasjonsskrivet endres dersom det er ment å være til både barn og foresatte (barna blir bedt om å signere samtykkeerklæringen).

2. Informasjonsskrivet bør starte med forespørsel om å delta, ikke "Kan dere hjelpe oss til økt kunnskap…

3. "Formuleringer som "vi håper dere returnerer…så snart som mulig" og "på forhånd takk for hjelpen" bes strøket da de er ledende.

4. Det må stå eksplisitt at forsøkspersonene kan trekke seg uten å oppgi grunn.

5. Personer som ikke ønsker å delta i studien skal ikke aktivt måtte takke nei (da samtykke skal innhentes i en klasseromssituasjon vil dette likevel bli kjent).

6. Data i studien er avidentifiserte, ikke anonyme, da prosjektleder har tilgang til nøkkelen.

7. Setningen: Vi spør om dere og deres barn vil hjelpe oss gjennom å delta bør endres til vi spør om dere vil delta i undersøkelsen…

8. Det mangler informasjon om at cytokiner skal måles.

9. Det mangler informasjon om at biologiske prøver kan trekkes fra studien dersom man ønsker dette.

10. Navn på biobankansvarlig bør oppgis slik at man vet hvem som skal kontaktes for å trekke prøver.

11. Det mangler informasjon om hvor lenge barna må faste (6 timer?).

12. Gi informasjon til foreldrene om hvordan eventuelle patologiske blodprøveverdier vil bli fulgt opp.

Vedtak:

"Under forutsetning av tilfredsstillende tilbakemelding og revidert pasientinformasjon og søknad om forskningsbiobank, tilrås prosjektet gjennomført og forskningsbiobank opprettet. Komiteens leder og sekretær tar stilling til dette."

Med vennlig hilsen
Sigurd Nitter-Hauge
Sigurd Nitter-Hauge (sign)
Professor dr.med.
Leder

Tone Haug
Tone Haug
Rådgiver
Sekretær

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Dato: 11.01.05
Deres ref.:
Vår ref.: S-04305

Kost, aktivitetsvaner og helse blant barn og unge i Norge

Vi viser til brev datert 20.12.04 med vedlegg: revidert informasjonsskriv og samtykkeerklæring.

Komiteen takker for grundig og oversiktlig svar på merknader, og tar disse til etterretning.

Komiteen har ingen merknader til revidert informasjonsskriv og samtykkeerklæring.

Komiteen tilrår at prosjektet gjennomføres og forskningsbiobank opprettes.

Vi ønsker lykke til med prosjektet!

Med vennlig hilsen

Sigurd Nitter-Hauge (sign)
Professor dr.med.
Leder

Tone Haug
Tone Haug
Rådgiver
Sekretær

UNIVERSITETET I OSLO
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Elin Kolle
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Nettadresse: http://helseforskning.etikkom.no

Dato: 13.12.2010
Deres ref.:
Vår ref.: 2010/3127

Kartlegging av fysisk aktivitet blant barn og unge

Prosjektleder: Elin Kolle
Forskningsansvarlig: Norges idretthøgskole ved øverste ledelse

Saksfremstilling
Formålet med studien er å etablere et nasjonalt kartleggingssystem for fysisk aktivitet blant barn (9-15 år). Det skal i prosjektet spørres etter barnas høyde, vekt, fysiske aktivitetsnivå, kosthold, røykevaner, korrelater for fysisk aktivitet (faktorer som forteller om barna er aktive eller ikke), TV-vaner, PC-vaner og sovemønster. Det skal benyttes akselerometer i et belte rundt livet på forskningsdeltakerne. Det skal rekrutteres ca 3400 barn til studien via et utvalg skoler. Barnas etniske bakgrunn skal registreres. I studien skal man foreta en kobling mellom de innsamlede opplysningene om barna i prosjektet med SSBs sosialøkonomiske opplysninger om foreldrene. Alle data i studien er indirekte personidentifiserbare og skal lagres på avidentifisert på en forskningsfil. Avidentifisert i denne sammenhengen betyr «(.) personopplysninger der navn, fødselsnummer og andre personentydige kjennetegn er fjernet, slik at opplysningene ikke lenger kan knyttes til en enkeltperson, og hvor identitet bare kan tilbakeføres ved sammenstilling med de samme opplysninger som tidligere ble fjernet». Ved studiens slutt skal alle data i studien slettes.

Vurdering
Komiteen har vurdert forespørsel om fremleggelsplikt for prosjektet "Kartlegging av fysisk aktivitet blant barn og unge" med hjemmel i helseforskningsloven § 10, jf. forskningsetikkloven § 4.

Etter søknaden fremstår prosjektet som samfunnsvitenskapelig forskning, og faller derfor utenfor komiteens mandat, jf helseforskningsloven §2. Prosjektet er ikke fremleggelsespliktig, jf. Helseforskningsloven §10, jf forskningsetikkloven § 4 annet ledd.

Vedtak
Etter søknaden fremstår prosjektet ikke som et medisinsk og helsefaglig forskningsprosjekt, men som et samfunnsvitenskapelig prosjekt. Det omsøkte prosjektet faller derfor utenfor komiteens mandat jf. Helseforskningsloven § 2. Prosjektet er ikke fremleggelsespliktig, jf. Helseforskningsloven § 10 jf. Forskningsetikkloven § 4 annet ledd.

Vi gjør oppmerksom på at evt. innhenting av opplysninger til prosjektet kan være avhengig av at det innhentes samtykke, og at det for behandling av personopplysninger i prosjektet likevel kan være nødvendig med tillatelse fra personvernombudet for forskning eller Datatilsynet. REK oppfordrer derfor prosjektleder om å ta kontakt med Datatilsynet eller Norsk samfunnsvitenskapelig datatjeneste (NSD) for å avklare disse spørsmålene.

Med vennlig hilsen

Stein Opjordsmoen Ilner (sign.)
Professor dr. med.
Komitéleder

Katrine Ore

Katrine Ore
Komitésekretær/Rådgiver
REK Sør-Øst

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Dato: 03.01.2011
Deres ref.:
Vår ref.: 2010/3127

Kartlegging av fysisk aktivitet blant barn og unge

Prosjektleder: Elin Kolle
Forskningsansvarlig: Norges idretthøgskole ved øverste ledelse

Saksfremstilling
Formålet med studien er å etablere et nasjonalt kartleggingssystem for fysisk aktivitet blant barn (9-15 år). Det skal i prosjektet spørres etter barnas høyde, vekt, fysiske aktivitetsnivå, kosthold, røykevaner, korrelater for fysisk aktivitet (faktorer som forteller om barna er aktive eller ikke), TV-vaner, PC-vaner og sovemønster. Det skal benyttes akselerometer i et belte rundt livet på forskningsdeltakerne. Det skal rekrutteres ca 3400 barn til studien via et utvalg skoler. Barnas etniske bakgrunn skal registreres. I studien skal man foreta en kobling mellom de innsamlede opplysningene om barna i prosjektet med SSBs sosialøkonomiske opplysninger om foreldrene. Alle data i studien er indirekte personidentifiserbare og skal lagres på avidentifisert på en forskningsfil. Avidentifisert i denne sammenhengen betyr «(.) personopplysninger der navn, fødselsnummer og andre personentydige kjennetegn er fjernet, slik at opplysningene ikke lenger kan knyttes til en enkeltperson, og hvor identitet bare kan tilbakeføres ved sammenstilling med de samme opplysninger som tidligere ble fjernet». Ved studiens slutt skal alle data i studien slettes.

Vurdering
Komiteen har vurdert forespørsel om fremleggelsplikt for prosjektet "Kartlegging av fysisk aktivitet blant barn og unge" med hjemmel i helseforskningsloven § 10, jf. forskningsetikkloven § 4.

Etter søknaden fremstår prosjektet som samfunnsvitenskapelig forskning, og faller derfor utenfor komiteens mandat, jf helseforskningsloven §2. Prosjektet er ikke fremleggelsespliktig, jf. Helseforskningsloven §10, jf forskningsetikkloven § 4 annet ledd.

Vedtak
Etter søknaden fremstår prosjektet ikke som et medisinsk og helsefaglig forskningsprosjekt, men som et samfunnsvitenskapelig prosjekt. Det omsøkte prosjektet faller derfor utenfor komiteens mandat jf. Helseforskningsloven § 2. Prosjektet er ikke fremleggelsespliktig, jf. Helseforskningsloven § 10 jf. Forskningsetikkloven § 4 annet ledd.

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Med vennlig hilsen

Stein Opjordsmoen Ilner (sign.)
Professor dr. med.
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Vår dato: 04.02.2005 Vår ref: 200500162 PB /RH Deres dato: Deres ref:

KVITTERING FRA PERSONVERNOMBUDET

Vi viser til melding om behandling av personopplysninger, mottatt 24.01.2005. All nødvendig informasjon om prosjektet forelå i sin helhet 03.02.2005. Meldingen gjelder prosjektet:

12166	*Aktivitetsvaner og fysisk form blant barn og unge i Norge*
Behandlingsansvarlig	*Norges idrettshøgskole, ved institusjonens øverste leder*
Daglig ansvarlig	*Lars Bo Andersen*

Norsk samfunnsvitenskapelig datatjeneste AS er utpekt som personvernombud av Norges idrettshøgskole, jf. personopplysningsforskriften § 7-12. Ordningen innebærer at meldeplikten til Datatilsynet er erstattet av meldeplikt til personvernombudet.

Personvernombudets vurdering

Etter gjennomgang av meldeskjema og dokumentasjon finner personvernombudet at behandlingen av personopplysningene vil være regulert av § 7-27 i personopplysningsforskriften. Dette betyr at behandlingen av personopplysningene vil være unntatt fra konsesjonsplikt etter personopplysningsloven § 33 første ledd, men underlagt meldeplikt etter personopplysningsloven § 31 første ledd, jf. personopplysningsforskriften § 7-20.

Unntak fra konsesjonsplikten etter § 7-27 gjelder bare dersom vilkårene i punktene a) – e) alle er oppfylt:

a) førstegangskontakt opprettes på grunnlag av offentlig tilgjengelige registre eller gjennom en faglig ansvarlig person ved virksomheten der respondenten er registrert,
b) respondenten, eller dennes verge dersom vedkommende er umyndig, har samtykket i alle deler av undersøkelsen,
c) prosjektet skal avsluttes på et tidspunkt som er fastsatt før prosjektet settes i gang,
d) det innsamlede materialet anonymiseres eller slettes ved prosjektavslutning,
e) prosjektet ikke gjør bruk av elektronisk sammenstilling av personregistre.

Personvernombudets vurdering forutsetter at prosjektet gjennomføres slik det er beskrevet i vedlegget.

Behandlingen av personopplysninger kan settes i gang.

Ny melding

Det skal gis ny melding dersom behandlingen endres i forhold til de punktene som ligger til grunn for personvernombudets vurdering.

Selv om det ikke skjer endringer i behandlingsopplegget, skal det gis ny melding tre år etter at forrige melding ble gitt dersom prosjektet fortsatt pågår.

Ny melding skal skje skriftlig til personvernombudet.

Offentlig register

Personvernombudet har lagt ut meldingen i et offentlig register, www.nsd.uib.no/personvern/register/

Ny kontakt

Personvernombudet vil ved prosjektets avslutning, 31.12.2006, rette en henvendelse angående arkivering av data benyttet i prosjektet.

Vennlig hilsen

Bjørn Henrichsen

Pernilla Bollman

Kontaktperson: Pernilla Bollman tlf: 55583348

Vedlegg: Prosjektbeskrivelse

Norsk samfunnsvitenskapelig datatjeneste AS
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Vår dato: 27.01.2011 Vår ref: 25870 / 3 / JSL Deres dato: Deres ref:

TILRÅDING AV BEHANDLING AV PERSONOPPLYSNINGER

Vi viser til melding om behandling av personopplysninger, mottatt 25.12.2010. Meldingen gjelder prosjektet:

25870	*Nasjonalt overvåkingssystem fysisk aktivitet. Kartlegging av fysisk aktivitet og determinanter for fysisk aktivitet blant barn og unge i Norge - ungKAN2*
Behandlingsansvarlig	*Norges idrettshøgskole, ved institusjonens øverste leder*
Daglig ansvarlig	*Elin Kolle*

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, eventuelle kommentarer samt personopplysningsloven/-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/forsk_stud/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://www.nsd.uib.no/personvern/prosjektoversikt.jsp.

Personvernombudet vil ved prosjektets avslutning, 31.12.2012, rette en henvendelse angående status for behandlingen av personopplysninger.

Vennlig hilsen

Bjørn Henrichsen

Juni Skjold Lexau

Kontaktperson: Juni Skjold Lexau tlf: 55 58 36 01
Vedlegg: Prosjektvurdering

Personvernombudet for forskning

Prosjektvurdering - Kommentar

25870

Formål:
Prosjektet har som formål å kartlegge fysiske aktivitetsvaner og determinanter for fysisk aktivitet blant norske 6-åringer, 9-åringer og 15-åringer.

Utvalg:
Utvalget består av ca 3400 barn - et representativt utvalg av den norske befolknings 6-åringer (1. trinn), 9-åringer (4. trinn) og 15-åringer (10. trinn). Utvalget trekkes på skolenivå av SSB. Utvalget består videre av barnas foreldre og kroppslærere. Elevenes foreldre informeres skriftlig om prosjektet (jf. informasjonsskriv mottatt 20.01.2011) og samtykker skriftlig til barnets deltakelse. Elevene vil informeres skriftlig om prosjektet, og samtykker til deltakelse ved å fylle ut og levere spørreskjemaet. Kroppslærer informeres muntlig om prosjektet (jf. e-post mottatt 26.01.2011). Vi forutsetter at kroppslærer i tillegg får informasjon om navn og kontaktopplysninger til daglig ansvarlig (Elin Kolle) og behandlingsansvarlig institusjon NIH).

Metode og datainnsamling:
Det behandles sensitive personidentifiserende opplysninger om elevenes og foreldrenes helseforhold (jf. pol § 2 nr 8 bokstav c).

Opplysningene samles inn gjennom spørreskjema fra barn og foreldre, intervju med kroppslærer, aktivitetsmåler (akselerometer) fra barna, og måling av barnas høyde og vekt. Datamaterialet vil bli koblet til opplysninger fra SSB om foreldrenes utdanning, inntekt og landbakgrunn. Videre vil det fysiske skolemiljøet kartlegges og observeres.

Det registreres direkte personidentifiserende opplysninger om barna og foreldrene gjennom navn og fødselsnummer. Det registreres indirekte personidentifiserende opplysninger gjennom bakgrunnsopplysninger om foreldrene. Direkte personidentifiserende opplysninger lagres separat fra det øvrige datamaterialet, men kan kobles mot det øvrige datamaterialet ved hjelp av en referansekode som kun prosjektleder har tilgang til.

Det registreres indirekte personidentifiserende opplysninger om kroppslærer, gjennom bakgrunnsopplysninger som stilling, arbeidssted og utdanning.

Prosjektslutt og anonymisering:
Prosjektslutt er satt til 31.12.2012. Opplysninger om kroppslærer vil da bli anonymisert. Det øvrige datamaterialet oppbevares videre etter prosjektslutt i avidentifisert form, i påvente av en mulig oppfølgingsundersøkelse om 3-10 år. Utvalget vil da bli kontaktet igjen. Det avidentifiserte datamaterialet lagres hos Helsedirektoratet og Norges idrettshøgskole, mens koblingsnøkkel til de direkte personidentifiserende opplysningene lagres hos NSD.

Alle innsamlede opplysninger vil bli anonymisert i 2025, ved at direkte personidentifiserende opplysninger slettes, mens indirekte personidentifiserende opplysninger slettes eller grovkategoriseres på en slik måte at de ikke kan tilbakeføres til enkeltpersoner.

Norsk samfunnsvitenskapelig datatjeneste AS
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Vår dato: 17.03.2011 Vår ref: 25870 JSL/RF Deres dato: Deres ref:

ENDRINGSMELDING

Vi viser til endringsmelding mottatt 01.03.2011 for prosjekt:

25870 *Nasjonalt overvåkingssystem fysisk aktivitet. Kartlegging av fysisk aktivitet og determinanter for fysisk aktivitet blant barn og unge i Norge - ungKAN2*

Vi har registrert følgende endringer i prosjektet:

1. Vi har registrert at det vil bli inkludert spørsmål om høyde og vekt i spørreskjemaet til barna.
2. Vi har registrert at det vil bli inkludert spørsmål om utdannelse og fødeland i spørreskjemaet til foreldrene, i stedet for at disse opplysningene skal samles inn gjennom SSB.
3. Vi har registrert at foreldre vil motta informasjon om at de ikke kan fylle ut spørreskjema på vegne av den andre forelderen uten at det foreligger samtykke fra sistnevne til dette. Denne informasjonen vil bli formidlet via lærer.

Vi forutsetter at prosjektet for øvrig er uendret, og viser i den anledning til våre tidligere vurderinger.

Ta gjerne kontakt dersom noe er uklart.

Vennlig hilsen

Bjørn Henrichsen

Juni Skjold Lexau

Kontaktperson: Juni Skjold Lexau tlf: 55 58 36 01

Appendix 3:

Informed Consents.

Kjære elev og foreldre/foresatte!

Forespørsel om deltakelse i "ungKan2" – en kartleggingsundersøkelse av fysisk aktivitet blant barn og unge i Norge

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Vennligst klipp av og returner samtykkeskrivet nedenfor i svarkonvolutten til kontaktlærer.

Med vennlig hilsen

Elin Kolle postdoktor Norges idrettshøgskole	Sigmund Anderssen professor Norges idrettshøgskole

SAMTYKKESKJEMA

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Vennligst utfyll opplysningene nedenfor:
(Skriv tydelig med blokkbokstaver)

Barnets fornavn:………………………………………………………………………………

Barnets etternavn:..…………………………………………………………………………….

Barnets personnummer (11 siffer):……………………………………………………………….

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Du deltok i undersøkelsen i 2005-06, og vi ønsker med dette å invitere deg til å delta i denne oppfølgingsstudien.

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Appendix 4:

Form used to assess the number of permanent play facilities in the participating schools' outdoor play areas (**Paper III**).

Kartleggingsskjema for skolens utearealer ungKan2

Kryss av eventuelt i kombinasjon med ring rundt kryss

1.Landskap/ terreng, tomta som helhet:

a. Overveiende flat: ……. b. Overveiende hellende inn mot utearealene: ……. c. Overveiende hellende inn mot utearealene: ……. d. Overveiende småkupert: …….

2. Vegetasjon:

a. Overveiende åpent uten vegetasjon: ……. b. Noe vegetasjon, spredte trær og busker: ……. c. Rikelig med vegetasjon: …….

3. Romstruktur: Nb. oppstår som resultat av terrengformer, vegetasjon og bebyggelse:

a. Skolegården er åpen uten romdannelser eller lite tydelige grenser: ……. b. Til en viss grad inndelt i ulike og mer avgrensede rom: ……. c. Skolegården er variert med små og store rom: …….

4. Møblering – belysning. Oppgi antall eller kryss av for forekomst:

a. Ballanlegg: a.1 Områder for fotball (antall mål): ……. a.2 Ballbinge (stk): ……. a.3 Områder for håndball (antall mål): ……. a.4 Anlegg for basketball (antall kurver): ……. a.5 Sandvolleyball (antall nett): …….

b. Diverse annet: b1. Husker (antall seter): ……. b.2 Fugleredehuske (antall): ……. b.3 Sandkasser (antall): ………. b.4 Lekehus (antall): ……. b.5Karuseller (antall): ……. b.6 Hoppedyr (antall): ……. b.7 Sklier(sklier): ……. b.8 Klatrevegg (antall): ……. b.9 Klatrestativ (antall): ……. b.10 Skateboard: ……. b.11 Bordtennisbord (antall): ……. b.12 Turnanlegg: ……. b.13 Annet: ………………………………………….

c. Anlegg for vinteraktiviteter: c.1 Skøyter:……. c.2Skilek: …….

d. Belysning: d.1 På gangarealer: ……. d.2. På bruksområdene: ....

5. Universell utforming:

a. Trinnfrie adkomster til inngangsdører og uteanlegg: Ja: ……. Nei: …….

b. Spesiell tilrettelegging ute for funksjonshemmede (intervju på stedet med NIHs kontaktperson):
Ja: …….. Nei: ………. Kommentarer: …….

6. Lokalklima og Solforhold: Intervju på stedet med NIHs kontaktperson

a. Solforhold: Er området så skyggefullt at det hemmer uteopphold/ fysisk aktivitet: Ja: ……. Nei: …….

b. Lokalklima- vind: Er området så vindutsatt at det hemmer uteopphold? Ja: ……. Nei: …….

7. Organisering av uteoppholdet: intervju på stedet med NIHs kontaktperson

a. Får elevene benytte arealer utenfor skolegården i friminuttene? Ja: ……. Nei: …….

b. Er utearealet sonedelt i forhold til aldersgrupper/ klassetrinn: Ja: ……. Nei: …….

c. Har alle klassetrinn samme friminutt-tid: Ja: ……. Nei: …….

d. Får eleven være inne i store friminutt: Ja: ……. Nei: …….

Kommentarer:………

Appendix 5:

Questions and possible answers from the questionnaire used to asses sleep duration, screen time, active school travel and sports/exercise participation (**Paper IV**).

Sleep duration	
When to you usually get out of bed on schooldays?	□ Before 06:30, □ Between 06:30 and 07:00, □ Between 07:00 and 07:30, □ Between 07:30 and 08:00, □ After 08:00[1]
When do you usually go to bed on schooldays?	□ Before 20:00, □ Between 20:00 and 21:00, □ Between 21:00 and 22:00, □ Between 22:00 and 23:00, □ Between 23:00 and 24:00, □ After 24:00[2]
Screen time	
How many hours do you usually watch TV before school?	□ None, □ Less than 1 hour, □ Between 1 and 2 hours, □ More than 2 hours
How many hours do you usually watch TV after school?	□ None, □ Less than 1 hour, □ Between 1 and 2 hours, □ Between 2 and 3 hours, □ Between 3 and 4 hours, □ More than 4 hours[3]
How many hours do you usually spend on a PC (to play games or surf the internet) or with a videogame (PlayStation, X-box or similar) on a weekday?	□ None, □ Less than 1 hour, □ Between 1 and 2 hours, □ Between 2 and 3 hours, □ Between 3 and 4 hours, □ More than 4 hours[4]
Active transport	
How do you usually get to school this time of year?[5]	□ By car or motorcycle, □ By bus, tram, metro or train, □ Cycle, □ Walk
How long does it usually take you to get to school?	□ Less than 5 minutes, □ 6-15 minutes □ 16 to 30 minutes, □ 31 minutes to 1 hour, □ More than 1 hour
Sports/exercise	
Outside of school: How many hours per week do you do sports/exercise that makes you breathe hard or sweat?	□ 0 hours, □ 1-2 hours, □ 3-4 hours, □ 5-7 hours, □ 8-10 hours, □ 11 hours or more

[1] In PANCS1, the highest category was "after 07:30"
[2] In PANCS1, the highest category was "after 22:00"
[3] In PANCS1, the highest category was "more than 3 hours"
[4] In PANCS1, the highest category was "more than 3 hours"
[5] "this time of year" was not specified in PANCS1

Appendix 6:

Cross-sectional and prospective associations between 30 and 60 min/day substitutions of sedentary time, body mass index and waist circumference.

Table S3: Cross-sectional and prospective associations between 30 min/day substitutions of sedentary time, body mass index and waist circumference.

Replacing 30 min/d^{-1} of sedentary time with 30 min/d^{-1} of:	n	Body mass index (BMI (kg·m^{-2})) β (95% CI)	n	Waist circumference (WC (cm)) β (95% CI)
Cross-sectional analyses[a]				
6-year-old girls				
Light PA	505	0.31 (0.11, 0.51)**	495	0.86 (0.39, 1.34)**
Moderate PA	505	-0.54 (-1.05, -0.04)*	495	-1.42 (-2.55, -0.30)*
Vigorous PA	505	-0.64 (-1.74, 0.47)	495	-0.44 (-3.60, 2.71)
6-year-old boys				
Light PA	485	0.25 (0.05, 0.44)*	475	0.46 (-0.05, 0.98)
Moderate PA	485	0.10 (-0.15, 0.36)	475	0.19 (-0.48, 0.86)
Vigorous PA	485	-0.97 (-2.13, 0.18)	475	-2.36 (-5.03, 0.31)
9-year-olds				
Light PA	2445	0.14 (0.06, 0.22)**	2423	0.52 (0.29, 0.76)**
Moderate PA	2445	-0.25 (-0.44, -0.06)*	2423	-0.96 (-1.37, -0.55)**
Vigorous PA	2445	-2.50 (-3.13, -1.88)**	2423	-5.38 (-7.09, -3.68)**
15-year-olds				
Light PA	1592	0.08 (-0.05, 0.21)	1544	0.52 (0.18, 0.85)**
Moderate PA	1592	0.19 (-0.07, 0.46)	1544	0.06 (-0.59, 0.72)
Vigorous PA	1592	-1.68 (-2.61, -0.75)**	1544	-3.23 (-5.83, -0.63)*
Prospective analyses[b]				
Light PA	503	0.16 (-0.01, 0.34)	476	0.22 (-0.25, 0.69)
Moderate PA	503	-0.16 (-0.43, 0.11)	476	-0.27 (-1.12, 0.59)
Vigorous PA	503	0.49 (-0.50, 1.48)	476	-1.30 (-3.86, 1.27)

[a] Adjusted for sex (not in analyses of 6-year-olds), age and accelerometer wear time.

[b] Adjusted for sex, age at baseline, follow-up time and BMI/WC at baseline.

*p≤0.040, ** p≤0.003

CI, confidence interval; PA, Physical activity.

Table S4: Cross-sectional and prospective associations between 60 min/day substitutions of sedentary time, body mass index and waist circumference.

Replacing 60 min/d^{-1} of sedentary time with 60 min/d^{-1} of:	n	Body mass index (BMI (kg·m^{-2})) β (95% CI)	n	Waist circumference (WC (cm)) β (95% CI)
Cross-sectional analyses[a]				
6-year-old girls				
Light PA	505	0.62 (0.21, 1.03)**	495	1.72 (0.78, 2.67)**
Moderate PA	505	-1.09 (-2.09, -0.08)*	495	-2.84 (-5.09, -0.60)*
Vigorous PA	505	-1.27 (-3.48, 0.94)	495	-0.88 (-7.19, 5.42)
6-year-old boys				
Light PA	485	0.50 (0.11, 0.88)*	475	0.93 (-0.10, 1.96)
Moderate PA	485	0.21 (-0.31, 0.72)	475	0.38 (-0.97, 1.73)
Vigorous PA	485	-1.95 (-4.26, 0.37)	475	-4.72 (-10.06, 0.63)
9-year-olds				
Light PA	2445	0.28 (0.13, 0.44)**	2423	1.05 (0.58, 1.52)**
Moderate PA	2445	-0.50 (-0.89, -0.12)*	2423	-1.92 (-2.75, -1.10)**
Vigorous PA	2445	-5.01 (-6.26, -3.75)**	2423	-10.77 (-14.18, -7.36)**
15-year-olds				
Light PA	1592	0.17 (-0.09, 0.43)	1544	1.04 (0.37, 1.71)**
Moderate PA	1592	0.39 (-0.14, 0.92)	1544	0.13 (-1.19, 1.44)
Vigorous PA	1592	-3.36 (-5.22, -1.49)**	1544	-6.46 (-11.67, -1.25)*
Prospective analyses[b]				
Light PA	503	0.33 (-0.01, 0.67)	476	0.44 (-0.51, 1.38)
Moderate PA	503	-0.32 (-0.87, 0.23)	476	-0.53 (-2.24, 1.17)
Vigorous PA	503	0.98 (-1.01, 2.97)	476	-2.59 (-7.71, 2.53)

[a] Adjusted for sex (not in analyses of 6-year-olds), age and accelerometer wear time.

[b] Adjusted for sex, age at baseline, follow-up time and BMI/WC at baseline.

*p≤0.040, ** p≤0.003

CI, confidence interval; PA, Physical activity.

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