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Sedentary behaviour in young people

Assessment methods and predictors

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Sammendrag på norsk

Innledning: Barn og ungdommer tilbringer mye av sin våkne tid sedate, og studier har vist at sedat atferd kan ha en negativ påvirkning på flere helsevariabler. Flere studier har undersøkt korrelater for sedat atferd hos barn og unge, men mindre kunnskap finnes om predikerende faktorer som er tilstede tidlig i livet. Sedat atferd måles ofte ved hjelp av et akselerometer, og de nye målerne kan uttrykke data i råformat, istedenfor «tellinger». Det er imidlertid usikkert om data fra ulike modeller og plassering er sammenlignbare, samt hvilke grenseverdier som skal benyttes for sedat atferd.

Hensikten med studien: Det overordnede målet med denne avhandlingen var å øke vår kunnskap om 1) sammenlignbarheten mellom rå triaksial akselerometerdata fra to forskjellige akselerometre og plasseringer, i tillegg til å utvikle og validere grenseverdier for sedat atferd uttrykt i rådata, og 2) hvorvidt faktorer under fosterlivet, fødsel og tidlig liv (<6 år) predikerer sedat atferd hos barn og unge.

Metode: Denne avhandlingen er basert på tre separate studier. I den første studien (**artikkel I og II**) sammenlignet vi rådata fra ActiGraph (AG) og GENEActiv (GA) båret på hofte og håndledd, i tillegg til å undersøke akselerometerets evne til å måle sedat atferd blant barn og voksne i det virkelige liv. I den andre studien (**artikkel III**) brukte vi data fra åtte observasjonelle studier fra the International Children's Accelerometry Database bestående av 10,973 barn og unge 6-18 år gamle, for å undersøke sammenhengen mellom fødselsvekt og sedat atferd, og om sammenhengen er mediert av sentral fedme (**artikkel III**). I den tredje studien (**artikkel IV**) gjennomførte vi en systematisk oversiktsartikkel for å undersøke om ulike faktorer under fosterlivet, fødsel og tidlig liv (<6 år) predikerer sedat atferd hos barn og unge.

Hovedresultater: Resultatene fra **artikkel I** viste en signifikant forskjell i akselerasjonsverdier mellom hofte- og håndleddsplassering. Det var ingen hovedeffekt av akselerometermerke hos voksne, men det ble funnet en tre-veis interaksjon og systematiske feil mellom merkene hos barn. **Artikkel II** viste at alle grenseverdier overestimerte sedat tid sammenlignet med activPAL (AP). Sensitivitet (Se) og spesifisitet (Sp) for de utviklede grenseverdiene under frittlevende aktivitet var lav for begge aldersgrupper og plasseringer (Se, 68-97%, Sp, 26-59%). Resultatene fra mediator-analysen i **artikkel III** viste at det var en signifikant indirekte effekt av fødselsvekt på sedat atferd gjennom sentral fedme, og effekten av fødselsvekt på sedat atferd ble redusert med 32% når analysene ble kontrollert for sentral fedme. Totalt 16 studier som undersøkte 10 ulike prediktorer ble inkludert i **artikkel IV**. To studier viste at arvelighet og BMI hos barn 2-6 år gamle var signifikante prediktorer for sedat atferd, mens fire og syv studier viste at gestasjonsalder og fødselvekt, respektivt, ikke var assosiert med sedat atferd senere i livet.

Konklusjon: Akselerometerdata fra AG og GA synes å være sammenlignbare ved samme plassering hos voksne, men ikke hos barn (**artikkel I**). Laboratorieutviklede grenseverdier overestimerer i allminnelighet frittlevende sedat tid sammenlignet med AP, med lav spesifisitet for alle grenseverdier (**artikkel II).** Sammenhengen mellom fødselsvekt og sedat atferd er delvis mediert av sentral fedme (**artikkel III**). Arvelighet og BMI i tidlig barndom kan predikere sedat atferd blant barn og unge. På grunn av få studier og metodiske begrensninger, er det vanskelig å konkludere om de andre faktorene predikerer sedat atferd (**artikkel IV**).

Stikkord: Sedat atferd, stillesittende tid, barn, ungdom, akselerometer, grenseverdier, fødselsvekt, determinanter, BMI

Summary

Introduction: Both children and adolescent spend a lot of their awake time sedentary, and studies have shown that sedentary behaviour may be detrimental to health. Several studies have examined correlates for sedentary behaviour in young people, however, less knowledge exist about early life predictors for this behaviour. Accelerometers are often used to measure sedentary time, and the newer versions collect data in its raw format, instead of "counts". However, it is uncertain whether output from different brands and placements are comparable, and which raw sedentary thresholds should be used.

Aim: The main aim of this dissertation was to increase our knowledge about 1) comparability between raw tri-axial accelerometer output from two different accelerometer brands and placements, in addition to develop and validate sedentary thresholds expressed in raw data, and 2) whether prenatal, birth and early life factors (<6 years) predict sedentary behaviour in young people (≤18 years).

Methods: This dissertation is based on three separate studies. In the first study (**Paper I and II**) we compared raw accelerometer output from ActiGraph (AG) and GENEActiv (GA) worn at the hip and wrist and evaluated the monitor's ability to measure free-living sedentary time in children and adults. In the second study (**Paper III**), we used pooled data from eight observational studies from the International Children's Accelerometry Database, consisting of 10,973 children and adolescent (6-18 years), to examine the association between birth weight and sedentary time, and whether this association is mediated by central adiposity. In the third study (**Paper IV**), we performed a systematic review to summarise the evidence on whether prenatal, birth and early life factors (<6 years) predicts sedentary behaviour in young people (≤18 years).

Main results: The results from **Paper I** showed a significant difference in acceleration values between the hip and the wrist placement. There was no main effect of monitor brand in adults, however, a three-way interaction and systematic error between the brands was found in children. **Paper II** showed that all thresholds overestimated sedentary time relative to activPAL (AP). Sensitivity (Se) and specificity (Sp) for the developed thresholds during free-living was low for both age-groups, brands and placements (Se, 68-97 %, Sp, 26-59%). The mediation analyses from **Paper III** showed a significant indirect effect of birth weight on sedentary time through waist circumference, and the effect of birth weight on sedentary time was attenuated by 32% when waist circumference was controlled for. Finally, in **Paper IV** 16 studies, examining 10 different predictors, were included. Two studies suggest that heritability and BMI in children aged 2–6 years were significant predictors of sedentary behaviour later in life, while four and seven studies suggest that gestational age and birth weight are not associated with sedentary behaviour respectively.

Conclusions: Accelerometer output from AG and GA seem comparable when attached to the same body location in adults, however not in children (**Paper I**). Laboratory derived sedentary thresholds generally overestimate sedentary time compared with AP during free-living, with low specificity for all thresholds (**Paper II).** The association between birth weight and sedentary time appears partially mediated by central adiposity (**Paper III**). The results from the systematic review suggest that heritability and early childhood BMI may predict sedentary behaviour in young people, however, small number of studies included and methodological limitations limits the conclusion (**Paper IV**).

Key words: Sedentary behaviour, sitting time, children, youth, accelerometer, thresholds, birthweight, determinant, BMI

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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. Hildebrand M, van Hees VT, Hansen BH, Ekelund U. Age group comparability of raw accelerometer output from wrist- and hip-worn monitors. Med Sci Sports Exerc. 2014;46(9):1816-24.

II. Hildebrand M, Hansen BH, van Hees VT, Ekelund U. Evaluation of raw acceleration sedentary thresholds in children and adults. (under review)

III. Hildebrand M, Kolle E, Hansen BH, Collings PJ, Wijndaele K, Kordas K, Cooper AR, Sherar LB, Andersen LB, Sardinha LB, Kriemler S, Hallal P, van Sluijs E and Ekelund U on behalf of the International Children's Accelerometry Database (ICAD) Collaborators. Association between birth weight and objectively measured sedentary time is mediated by central adiposity: data in 10,793 youth from the International Children's Accelerometry Database. Am J Clin Nutr. 2015;101(5):983-90.

IV. Hildebrand M, Øglund GP, Wells JC, Ekelund U. Prenatal, birth and early life predictors of sedentary behaviour in young people: a systematic review. Int J Behav Nutr Phys Act. 2016:13:63. DOI 10.1186/s12966-016-0389-3

Abbreviations

AG	ActiGraph
AP	activPAL
BMI	Body mass index
CI	Confidence interval
cpm	Counts per minute
GA	GENEActiv
ICAD	the International Children's Accelerometry Database
ICC	Intraclass correlation
MEMS	Micro electro-mechanical system
MET	Metabolic equivalent of task
MVPA	Moderate-to-vigorous physical activity
NSSS	the Norwegian School of Sport Sciences
REE	Resting energy expenditure
SD	Standard deviation
VM	Vector magnitude
VO_2	Oxygen consumption
WC	Waist circumference

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Introduction

In today's society, both children and adults spend a considerable amount of their waking day sedentary (1-4), and the environment in developing countries, including workplaces, schools, homes and public places, are continuously being facilitated to minimize human movement and reduce energy expenditure (5). In the past, the health risks of having a sedentary lifestyle were thought to be a result of not performing enough moderate-to-vigorous physical activity (MVPA) (6). However, new evidence has emerged challenging this assumption, recognising sedentary behaviour as an independent risk factor for disease (7). It has been suggested that the metabolic and long-term health effects of sedentary activities, i.e. sitting too much, are different from those associated with not performing enough MVPA, i.e. too little activity (8). Both self-reported, mostly time spent viewing TV, and objectively measured sedentary time, have been found to be associated with adverse health outcomes, including cardio metabolic risk factors, mortality, depression, and self-esteem in young people and adults (9-12). As a result, several authorities have applied guidelines for reducing time spent sedentary (13).

Hence, given the high amount of time spent sedentary in young people and the potential harmful effects of excessive sedentary behaviour on numerous health outcomes, valid and accurate assessment methods are a prerequisite for being able to examine this field further. In addition, a better understanding of potential correlates and predictors of this behaviour is important to provide evidence for public health interventions aimed at reducing sedentary time. In this introduction, the first section is a description of definitions of various terminologies frequently used in the field of sedentary behaviour and physical activity research. In the next section, I move on to describe methods used to measure sedentary behaviour in young people (≤18 years) and adults, summarising advantages and limitations with each method. Thereafter, the association between sedentary behaviour and health in young people and whether this association is independent of physical activity will be addressed. In the last section, existing literature on correlates and predictors for sedentary behaviour in young people will be presented.

Sedentary behaviour and physical activity – definitions and dimensions

It is important to define terms often used in sedentary behaviour and physical activity research, since there are many different concepts and these are not always synonymous and should not be used interchangeably.

Sedentary behaviour/time

The word sedentary originates from the Latin word *sedentarius*, which means to sit. *Sedentary behaviour* and *sedentary time* are often used interchangeably and are most commonly defined as a distinct class of waking behaviour in a seated or recline posture with an energy expenditure ≤1.5 metabolic equivalent of task (MET) (14). This definition consists of two different types of concepts, including posture allocation and metabolic rate. The same posture allocation can serve many different types of sedentary behaviours, including sitting at school or sitting watching TV, while other types of sitting activities with a higher metabolic rate (e.g. cycling and rowing) are appropriately defined as physical activities (15).

Physical activity

Physical activity is a complex behaviour compromising numerous terms associated with bodily movement such as clapping hands, jumping, riding a bike or running and is often defined as "any bodily movement produced by skeletal muscles that result in energy expenditure" (16). It is often divided into different dimensions, the most commonly being *frequency* (number of activity bouts during a specific period), *duration* (the time of participation in a single activity bout) and *intensity* (the physiological effort involved in performing activity), which together make up the total volume of physical activity. Two other important dimensions of physical activity are *type/mode* and *domain*. *Type/mode* of physical activity regards the specific physical activity being performed, while the *domain* of physical activity is the context in which the activity takes place, including at home, school, school-break time and during sports or leisure time. In sedentary behaviour and physical activity research, it is important to differentiate between an individual that is *sedentary*, i.e. engaging in a large amount of daily sedentary behaviour, and an individual that is *physically inactive*, i.e. not meeting the recommended dose of physical activity according to public health recommendations (17).

Sedentary behaviour and physical activity outcomes

Sedentary behaviour can be expressed in a variety of different metrics, including time spent in different specific sedentary behaviours, total time spent sedentary and whether it is accumulated with or without breaks. In general, the most common measures of interest for sedentary behaviour and physical activity are intensity of activity (i.e. sedentary, light, moderate and vigorous) and time spent in these specific intensities. MET is a widely used absolute physiological term for expressing the intensity and it is the multiples of resting energy expenditure (REE), where the traditionally accepted value for 1 MET is 3.5 $mLO_2 \cdot kg^{-1} \cdot min^{-1}$ for adults. In children, the adult value for 1 MET is not appropriate to use since REE expressed in relation to body weight is substantially higher than in adults (4-7 $mLO_2 \cdot kg^{-1} \cdot min^{-1}$), and it is difficult to identify a single accepted value for 1 MET across a wide age range in young people (18, 19). Nevertheless, public health recommendations on physical activity intensities are often expressed as METs and in general, moderate intensity physical activity refers to 3-6 METs (20), which correspond to approximately 40-55% of maximal oxygen uptake or 60-70% of maximal heart rate (HR) in adolescents (21). Sedentary, light and vigorous physical activity corresponds to ≤1.5, 1.6-2.9, and >6 METs respectively.

How sedentary are young people?

Various studies have sought to determine how much time young people spend sedentary. The answer to this question at least partly depends on the assessment method and subsequent interpretation of the sedentary data. Different methods of measurement and analyses are not always comparable, making comparisons about sedentary levels across studies and populations challenging. Pate and co-workers (22) performed a systematic review including 76 studies to examine the amount of time spent sedentary in young people. For example, their results suggest that 35-56% of American children aged 2-15 years watched two or more hours of TV per day, and the amount increased with age (23). In Australia, 12-year-old girls spent 5 hours per day in self-reported sedentary behaviour and the time increased to 7 hours per day by 15 years of age (24). Included studies using an objective measure, such as the accelerometer estimate that 41 to 78% of awake time is spent sedentary in European children aged 7-15 years old (25, 26). In another systematic review, Downing and co-workers (2) examined the prevalence of sedentary behaviour in children <2 years, and their results suggest that between 17-98% of the children did not confirm with the zero screen time recommendation. The high levels of time spent sedentary reported in the studies are in accordance to studies showing that only a small portion of all young people meet the guidelines for physical activity, i.e. 60 minutes of moderate physical activity per day (1, 27-29).

Assessment of sedentary behaviour

Accurate assessment of sedentary behaviour and physical activity are important for several reasons, including examining dose-response relationships between sedentary behaviour, physical activity and several health outcomes; evaluating the effect of an intervention designed to for example decrease sedentary behaviour; and assessing levels, patterns and trends in sedentary behaviour and physical activity in surveillance studies (30). An imprecise measure of sedentary behaviour will attenuate the true effect, thus underestimating or mask the true association between the exposure and outcome. Earlier, sedentary behaviour was measured as the absence of MVPA, however, this is not an appropriate method and today there is a general consensus that sedentary behaviour should be measured specifically (31).

Since the definition of sedentary behaviour consists of two different types of concepts, including posture allocation and metabolic rate (14), one can choose to measure either posture, i.e. sitting or lying, or energy expenditure. Normally sedentary behaviour is assessed in one of three different ways; 1) a specific behaviour like computer time or TV-viewing, 2) in a specific domain, e.g. sedentary behaviour at school or leisure time, and 3) total amount of time spent sedentary (32). In general, methods can be divided into objective and subjective methods. Subjective methods such as questionnaires, interviews and activity diaries may be influenced by opinion and perception, from the participant, investigator or both. Objective methods, including accelerometers, inclinometers and indirect calorimetry, record a physiological or biomechanical parameter and uses this to estimate sedentary time and physical activity; these methods are not influenced by opinion or perception but are susceptible to measurement error (33).

This chapter will continue with a brief presentation of the most commonly used methods for assessing sedentary behaviour and accelerometers will be highlighted, since this is the main method used in this thesis.

Indirect calorimetry

Indirect calorimetry measures oxygen consumption (VO_2) and/or production of carbon dioxide and uses standard equations to predict energy expenditure as an estimate for energy expenditure (34). A facemask, mouthpiece or hood covering the head collects the expired air, and a stationed system next to the individual or a portable system mounted on the individual's body analyses the gas. This method is considered as a valid measure of short term energy expenditure and is frequently used as the criterion method when validating heart rate monitors, pedometers and accelerometers in laboratory and free-living settings for a limited time (35). The disadvantage with this method is that the equipment is usually stationary, hence it is not suitable to measure free-living behaviour. However, there are portable systems on the market but the equipment is still too cumbersome to use during prolonged periods.

Direct observation

Direct observation is a common applied method for assessing patterns of sedentary behaviour and physical activity and is sometimes considered as the gold standard for physical activity assessment in children (35). A trained observer observes the participants using one of many observational systems available to record the different behaviours in time intervals, e.g. every minute. Direct observation is suitable for assessing sedentary behaviour and physical activity in controlled environments, such as during school break-times, and for short-term validation studies (17). One advantage with observation is that the method does not rely on the participant's ability to recall sedentary behaviour and is therefore especially suited when assessing younger children. On the other hand, limitations with this method are the substantial investigator burden, the invasion of the individual's privacy, in addition to reactivity and consequently altered behaviour (Hawthorne effect).

Subjective methods

Subjective assessment methods such as questionnaires, diaries, logs or recalls are the most widely used methods for measuring different sedentary behaviours, in addition to physical activity (36). The main strength of subjective methods are that they can capture all aspects of sedentary behaviour, including specific behaviour, frequency, duration, the domain and the context with sedentary behaviour (37). Other advantages are easy administrating, relatively inexpensive and can be used in large sample sizes, in addition to that the methods do not alter the subject's behaviour. Questionnaires are arguably the cheapest and simplest method for assessing sedentary behaviour and physical activity in a large number of people in a short time. Numerous different questionnaires are being used in research today and many of the methods focus on one specific behaviour only, for example TV-viewing and screen time, and these methods can as a result not be used to measure overall time spent sedentary. The most important limitation of using a subjective method is that the method rely on the participant's ability to recall and assess time spent sedentary and physically active (38). A systematic review examining the validity and reliability of six tools used to measure sedentary behaviour in young people found correlation coefficients ranging from 0.30-0.40 with objective and criterion methods (39). Methods targeting specific behaviours in specific domains, for example TV-viewing often show greater correlations, which may be due to that they are less prone to recall bias than methods targeting overall sedentary time (32). Another limitation with some subjective methods are that they do not actually include more sedentary and routine behaviours, especially behaviours that are spontaneous and of short duration of time (40). Subjective methods are, as opposed to objective methods, usually developed to be used in specific groups and are therefore age and cultural specific. Questionnaires developed for adults may not be suited to assess sedentary behaviour and physical activity among young people. In addition, children below 10 to 12 years of age are less likely to provide accurate self-report data and therefore parental or teacher-reported questionnaires or proxy-reports are often used. However, recollection of children’s sedentary behaviour is difficult for adults and unique limitations and errors are associated with this method as neither a parent nor teacher will be able to constantly monitor any one child for elongated periods and they may also be in charge of other children (41). Finally, several of the studies validating for example questionnaires have used accelerometers or logs as the criterion method. These methods have their own sources of measurement errors, which represents a problem when interpreting the results and the validity of self-report methods (39).

Objective methods

Objective measurement methods such as accelerometers and inclinometers are not influenced by the individual's self-assessment of sedentary behaviour and physical activity, and may thus be less prone to recall and social desirability bias. Especially accelerometry are becoming more common to assess both sedentary time and physical activity, even in large-scale epidemiological studies.

Inclinometers

Inclinometers are small, lightweight uniaxial accelerometers, normally worn on the anterior mid-line of the thigh, and have recently received increased attention as a suitable assessment method for assessing duration of sedentary time, in addition to physical activity (42, 43). The device uses accelerometer-derived information to assess thigh orientation with respect to gravity to determine time spent in different posture allocations, including lying/sitting, standing, postural changes (sit-to-stand) and walking (including all activity-related acceleration). Numerous studies have evaluated the criterion validity of an inclinometer named activPAL (AP) against direct observation during laboratory activities in both children (42-44) and in adults (45-47). Overall, the AP has shown a high agreement with direct observation, with sensitivity and specificity values between 87-100 % and 80-100 % respectively (43, 48). Another advantage with an inclinometer is that it is usable in all age groups, including young children. However, there are some limitations to the inclinometer that needs to be addressed. First, daily activities consist of many different movements and are not limited to the three standardised postures that an inclinometer can detect (lying/sitting, standing and walking), e.g. squatting, crawling and kneeling up. This is especially relevant when measuring postures in children (49). In addition, postural misclassification of sitting as standing has been reported (43), possibly explained by the set degree used by the proprietary algorithms to distinguish between the horizontal and vertical position of the thigh.

Accelerometers

Acceleration is a change in velocity over time (m/sec^2) and it can be measured by small, lightweight and portable devices that record movement in one or several planes of the body segment to which it is attached. The acceleration produced during movement is proportional to the net internal muscular forces used and therefore the acceleration can be used as an estimate of the energy cost of the movement (50). The monitor is commonly worn on the hip, as this is the closest place to the centre of gravity of the body. However, recently there has been a shift towards a wrist placement since it has numerous advantages, including greater user acceptability among individuals, leading to greater compliance and less loss of data, and the ability to measure upper body movement (51, 52).

In general, the accelerometer is worn during waking hours and removed for sleeping, in addition to showering and swimming if the monitor is not waterproof. Normally the monitor should be worn for 4–7 continuous days, including both weekdays and weekends (53, 54), since activity patterns may differ between week- and weekend days (55). In addition, a minimum of 8-10 hours per day of registered movement is required to reflect the entire day (56, 57). Data when the monitor is not worn can be excluded by deleting data consisting of continuous zeros. The number of zeros chosen may increase with age due to the sporadic and frequent nature of young children's physical activity. Different protocols and definitions of non-wear time varies between studies, and this can have substantial impact on sedentary and activity outcomes (57-59).

However, several studies support the use of a minimum 60 minutes of consecutive zeros as a criterion for non-wear time in young people (57, 59).

There are several advantages of using accelerometers, including the ability to measure the entire range of activities, from sedentary to vigorous activities, and that the monitors can provide objective information about patterns of sedentary behaviour and physical activity, including frequency, intensity and duration (60). Moreover, the monitors are small, easy to use for the individuals and not too expensive to be used in large sample sizes. The disadvantages with accelerometers are disability to capture type of behaviour, as well as the context of the behaviour being performed. In addition, energy expenditure is often underestimated due to external work and the monitor's inadequate capability to capture activity with little or no movement of the body segment where the monitor is attached (61, 62). Finally, accelerometers estimate time spent sedentary by the absence of movement, and can therefore not discriminate between sedentary activities (e.g. sitting) and non-sedentary activities (e.g. quit standing) if no movement is happening where the monitor is attached.

To date multiple devices are being used to assess free-living sedentary time and physical activity in large scale epidemiological studies, including the most commonly used ActiGraph (AG), followed by the GENEActiv (GA). The first version of AG, named Computer Science and Application (CSA) came on the market in 1992. An accelerometer mechanically captures acceleration and converts it to an electrical signal. The older versions of AG used a horizontal cantilevered beam with a weight on it (63). Acceleration in the vertical plane caused the beam to bend and compress a piezoelectric crystal, which produced a voltage proportional to the acceleration. The newer versions of AG, the GT3X+ (4.6 x 3.3 x 1.5 cm, 19 g) and the GA (4.3 x 4.0 x 1.3 cm, 16 g) are tri-axial accelerometers (vertical, anteroposterior and mediolateral axis) that uses a micro electro-mechanical system (MEMS) instead of a beam to produce an electrical signal. The newer monitors measure acceleration between $-6g$ and $+6g$ (AG) or $-8g$ and $+8g$ (GA), and the output from the monitors are digitised by a 12-bit analogue-to-digital converter at a user-specified rate ranging from 30 to 100 Hz.

Choosing the most accurate and appropriate method for the interpretation of accelerometry data is possibly one of the biggest challenges facing researchers, due to the multitude and variety of published methods (64). The primary outcome from an accelerometer is acceleration expressed as units of gravity (g, where $1g=9.81\ \mathrm{m{\cdot}s^{-2}}$), and the new versions of the monitors collect data in its raw format in three planes. However, the older versions of accelerometers only provided data expressed in *counts* per unit of time (epochs) or *counts per minute* (cpm) and therefore the majority of studies using accelerometers expresses their data in these units. Counts is an arbitrary value that is not comparable between monitor brands and that is influenced by the amplitude and frequency of acceleration (Matthew, 2005; Reilly et al., 2008). A low number of cpm indicate low level or low intensity of activity, whereas a high number of cpm indicates high level or high intensity of activity (27). Cpm can be translated into time spent in different intensities (i.e. sedentary, light, moderate and vigorous intensity) by using cut-points that are equivalent to different activity intensities. The vast majority of calibration studies conducted to derive intensity cut-points from accelerometer counts have measured VO_2 during treadmill walking and running and/or a combination of lifestyle activities performed in the laboratory (65). However, specific activities performed during a limited time in the laboratory may not accurately reflect all activities performed during free-living and when used in the field, cut-points derived during flat treadmill activities tend to underestimate physical activity energy expenditure (66). Therefore, calibration studies have also been performed during free-living activities to be generalizable to the full range of activities encountered in daily life. Nonetheless, the included activities in any calibration study will affect the relationship between accelerometer counts and energy expenditure, which has resulted in a wide variety in published intensity cut-points, affecting the comparability between studies. In young people and for the AG, the lower cut-points for moderate intensity activity range from 615–3581 cpm (60, 67). When used in the same population, the diverse cut-points can give substantially different results regarding activity level and estimates of energy expenditure (68-71). Unfortunately, there is no consensus on which cut-points expressed in counts to use and consequently, the field of accelerometry has been fragmented by inconsistency in data calibration and the conversion of accelerometer raw output into counts.

There has also been published different cut-points for sedentary activities, ranging from 100–1100 cpm in young people. (67, 72). However, there seems to be mounted evidence that a cut point of 100 cpm is acceptable to use in both children and adults and this cut point is widely and predominantly applied in studies examining the association between health and sedentary time measured by accelerometers in children and adults (73, 74). Treuth and co-workers (72) were one of the first studies to validated 100 cpm as a threshold for sedentary activities. In their study, 74 girls aged 13-14 years performed 10 activities, ranging from sedentary activities like TV-viewing to more vigorous activities like running, while VO_2 was measured through indirect calorimetry. The results suggest that a lower threshold for light activity of 50 counts per 30 seconds showed a perfect specificity and sensitivity and by default <100 cpm was defined as a sedentary cut-point.

These results have later been supported by other studies in both children and adults (47, 70, 75, 76).

Sedentary behaviour and health

During the last decade, there has been a large increase in the amount of epidemiological studies examining the relationship between sedentary behaviour and health in young people, including both physical, psychosocial and behavioural health factors (77) . Most of the studies are of a cross-sectional design examining one or several specific self-reported sedentary behaviours, for example TV-viewing or computer use, but the number of studies using objective measurements are increasing. However, several studies have defined sedentary as not meeting a criterion level for physical activity and therefore not measured sedentary activities adequately (6). In addition, only a small amount of the studies has examined the relationship between sedentary behaviour and health, independent of physical activity.

The majority of studies performed have focused on the association between one specific sedentary behaviour, the most common being TV-viewing and health. Several systematic reviews, including both cross-sectional, longitudinal and randomized controlled trials, have shown very low to moderate evidence for a positive association between self-reported screen-time and weight status in younger children (0-4 years) (78), adolescent girls (12-18 years) (77) and in young people (≤18 years) (9, 79-82). There is also very low to moderate evidence for an adverse association between screen-time and physical fitness (77, 81, 83), mental health (77, 84), self-esteem (9, 81), cardiovascular disease risk factors (9, 81), social behavioural problems (81) and cognitive development (78, 85). The major limitation with studies examining one specific sedentary behaviour is that the relationship between sedentary behaviour and health could be affected by other factors strongly connected to the specific behaviour. It is possible that screen-time is connected to other unhealthy lifestyles, and two review articles concludes that sedentary behaviour, predominantly TV-viewing, is related with unhealthy dietary behaviours in young people (77, 86). Taking into account that diet is an even more complex behaviour to measure than sedentary behaviour and physical activity and that it is often self-reported using methods not validated, it is uncertain how much of the association between TV-viewing and other screen time behaviours and health is mediated by diet.

TV-viewing has been shown to be a poor measure of overall sedentary time and therefore conclusions from such studies are limited to this specific behaviour and should not be used to draw conclusions about the relationship between overall sedentary behaviour and health (6). One systematic review by Tanaka and co-workers (87) showed that there was little evidence for an association between longitudinal changes in objectively measured sedentary time and adiposity in children and adolescents. These results are also supported by other systematic reviews and meta-analyses showing no or limited evidence for an association between objectively measured sedentary time and weight status in young people (9, 82, 88). Insufficient evidence has also been found for an association between objectively measured sedentary time and cardio metabolic risk factors, fitness and self-esteem (9, 82). One explanation for these results, is that it is difficult to establish an association between the exposure and outcome when the variables are measured with different degree of precision. For example, measures of adiposity and weight status are much more precise than measures of sedentary time, and when the more imprecise variable is used as the exposure, the magnitude of the association will be attenuated, hence showing a weak or no association. Finally, studies have shown that it is not only important to examine total amount of sedentary time, but also the manner in which it is accumulated (short versus long bouts) (89, 90). For example in adults, it has been shown that interrupting sitting time with 2-minute bouts of light or moderate intensity walking lowered postprandial glucose and insulin levels in overweight adults compared to uninterrupted sitting (89). Whether these findings apply for young people remains to be determined, since the association between different patterns of sedentary time and health outcomes is less examined in young people (9).

It is generally accepted that to examine the independent effect of sedentary time on health outcomes, analyses should be adjusted for physical activity. Since sedentary time and total physical activity time are perfectly inversely correlated, sub-components of physical activity such as MVPA are often used. Several of the studies included in the previously mentioned systematic reviews do not state if the results are adjusted for physical activity, or other confounders, and hence the effect of sedentary behaviour on health, independent of physical activity, is more limited. One large study consisting of pooled data from 14 studies, including more than 20,000 children aged 4-18 years, examined the independent and combined association between objectively measured sedentary time and MVPA and cardio metabolic risk factors (91). The results showed that sedentary time was not associated with systolic blood pressure, insulin or any of the other outcomes independent of time spent in MVPA. In another cross-sectional study accelerometer measured sedentary time was not statistically associated with cardio metabolic risk factors in Canadian children aged 8–10 years when adjusting for MVPA (92). These results are supported by a systematic review that examined the association between volume and pattern of objectively measured sedentary time and markers of cardio-metabolic risk in youth (age 6-19 years) (93). A total of 45 articles were included and the review found little evidence for an association between sedentary time and cardio-metabolic risk when adjusting for MVPA. However, the study showed that self-reported screen time was positively associated with waist circumference and negatively associated with HDL cholesterol independent of MVPA, suggesting that a specific sedentary behaviour might be more important than overall sedentary time in relation to cardio metabolic risk (92). Further, recent work suggests that time spent sleeping and in physical and sedentary activities are collinear and not independent, even if they are uncorrelated (e.g. sedentary time and MVPA) (94). Therefore, adjustment of physical activity (e.g. MVPA) when examining the association between sedentary behaviour and health could be erroneous, and novel approaches such as compositional analyses to examine the relative effect of sedentary behaviour by allocating time of these different behaviours (i.e. sedentary time, light physical activity and MVPA) (94) might be more correct. However, this has up till now not been done among young people.

In summary, there is some evidence showing that screen-time sedentary behaviour is associated with several negative health effects in young people. However, many of the studies have numerous limitations, including cross-sectional design, limitations associated with self-report methods and risk of bias. There are a few studies using accelerometers to assess sedentary time, which is less prone to measurement errors than self-report methods, and quite the contrary these studies show that sedentary time is not associated with different health outcomes. Further evidence is required to get better knowledge about the causal relationship between sedentary behaviour and health, and the relative contribution of sedentary time and physical activity on health outcomes in young people.

Correlates and predictors for sedentary behaviour

To be able to implement effective interventions and strategies to reduce sedentary behaviour in young people, knowledge about factors predicting this behaviour are essential. In 2015 there was published a systematic review examining predictors and determinants of sedentary behaviour in young people (95). The review included 37 studies, mostly conducted in Europe (n=13) and USA (n=11), and the results showed that age was positively associated with total sedentary behaviour, which has also been supported in an earlier review (96). Weight status and baseline assessment of screen time were positively associated with later screen time. Further, less evidence was found for an association between a higher playground density and availability of play and sports equipment at school and increased total sedentary behaviour, and between safe places to cross roads and lengthening morning and lunch breaks and decreased total sedentary behaviour (95).

These previous systematic reviews have mainly focused on environmental, social, behavioural and policy factors during childhood and adolescence (>6 years of age) as determinants of later sedentary behaviour (95, 96). However, studies have shown that high amounts of sedentary time are present already in younger children (3-5 years of age) (97), that this behaviour increases during childhood (98, 99) and tracks from childhood to adolescent and adulthood (100), suggesting that important factors associated with sedentary behaviour may manifest very early in life, perhaps already during the fetal period or at birth. According to the Developmental Origins of Health and Disease hypothesis, non-optimal growth and environmental conditions during fetal life and early childhood may result in permanent changes in the body's structure, function and metabolism (101). These adaptations, potentially caused by epigenetics and irreversible, may lead to increased risk of diseases and an altered behaviour later in life. For example, birth weight, which is used as a marker of intrauterine growth restriction and the intra-uterine environment, is inversely associated with the risk of cardiovascular disease (102, 103), type 2 diabetes (104), and all-cause mortality (105). Furthermore, results from animal studies suggest that the offsprings of undernourished mothers are less active and more sedentary compared with normal offsprings (106, 107), and the underlying mechanism for this association might be due to remodelling of the hypothalamus through alterations in availability of nutrients or hormonal signalling (106). Another possible hypothetical pathway between prenatal, birth and early life factors and sedentary behaviour might be through excessive adiposity tissue. For example, high and low birth weights (108-112) and specific genes (113) are all predictors of later obesity, which might constrain physical movement (114) and lead to a sedentary lifestyle. Several prenatal, birth and early life factors and their relation to sedentary behaviour later in life have been studied among young people, including heritability, birth weight, gestational age etc. However, no previous studies have tried to summarise this evidence in a systematic review.

Need for new information

Several large scale epidemiological studies have assessed free-living sedentary behaviour and physical activity among both children and adults using the newer versions of AG and the GA worn on the hip or the wrist. The use of different accelerometer brands and different placements in epidemiological studies requires comparability studies for accurate interpretation of data across studies. In addition, there is a need to develop cut-points for different activity intensities, expressed in raw tri-axial accelerometer data. Furthermore, young people are spending a lot of their time sedentary, and to be able to implement effective interventions and evidence-based sedentary behaviour guidelines and policies, increased knowledge about predictors acting during gestation, birth and early childhood (≤6 years) of sedentary behaviour are needed.

Aims of the dissertation

The overall aim of this PhD was to investigate accelerometry expressed in raw accelerometer output for assessing sedentary time and physical activity, and to investigate predictors for sedentary behaviour in young people. The specific aims of the separate papers were as follows:

1. To compare raw tri-axial accelerometer output from two accelerometers (ActiGraph and GENEActiv) and to determine whether the placement (hip and wrist) influences the accelerometer output during eight different activities in children and adults, in addition to develop regression equations for estimating energy expenditure from raw accelerometer output using indirect calorimetry as the reference method (**Paper I**).
2. To develop sedentary thresholds from hip and wrist raw tri-axial acceleration values using the ActiGraph and GENEActiv accelerometers in children and adults, in addition to examine the agreement between time spent sedentary using these thresholds compared with time spent sedentary from the activPAL accelerometer during free-living (**Paper II**).
3. To examine the relationship between birth weight and objectively measured sedentary time and whether this association is mediated by central adiposity in youth aged 6–18 years (**Paper III**).
4. To examine whether prenatal, birth and early life factors are predictors of sedentary behaviour by synthesising the evidence from observational research in young people ≤18 years old (**Paper IV**).

Methods

The four papers included in this dissertation were the result of three distinct research studies. In the first study (**Paper I and II**) we examined raw accelerometer output from two accelerometers worn at two placements and evaluated the monitor's ability to measure sedentary time and physical activity in children and adults. In the second study (**Paper III**) we used pooled data from the International Children's Accelerometry Database (ICAD) to examine the relationship between birth weight and sedentary time and whether this association was mediated by central adiposity in youth aged 6–18 years. In the third study (**Paper IV**), we performed a systematic review to summarise the evidence on whether prenatal, birth and early life factors predicts sedentary behaviour in young people (≤18 years). The three studies differ substantially in study design and methodological approach, and will be described separately.

Examination of raw tri-axial accelerometer output (Paper I and II)

Participants

The first study consisted of 30 adults (17 women) aged 21-61 years and 30 children (14 girls) aged 7-11 years. This was a convenience sample, with participants recruited from the staff and students from the Norwegian School of Sport Sciences (NSSS) and through social media. To be included, the participants had no contraindications to participation in physical activity, disorders affecting their energy expenditure or ability to perform the structured activities. The study falls outside the Regional Committees for Medical and Health Research Ethics (REC) and therefore did not require approval from the institution (Appendix I). Instead, the study was approved by the Norwegian Centre for Research Data (NSD), which is NSSS' Data Protection Official for Research (Appendix I). All participants, or the caregivers among those younger than 16 years completed a written informed consent before participation (Appendix II).

Protocol

Participants performed a protocol in the laboratory at the NSSS, which consisted of eight activities; two sedentary activities (lying in supine position and quiet sitting while using a computer), two mixed activities including both sitting and standing/walking (only used in **Paper I**) and four activities ranging from light to vigorous intensity (i.e. standing, slow and fast walking, and running). Each activity was performed for 5 minutes, except for lying down, which lasted for 10 minutes, and the activities were separated by a 1-minute break. After the laboratory-protocol, the participants were asked to wear the monitors for approximately 24 hours and only remove the monitors during water-based activities and while sleeping (free-living data used in **Paper II** only).

Measurements

Accelerometry

Each participant was fitted with five monitors; one ActiGraph GT3X+ (ActiGraph, Pensacola, FL, USA) (AG) and one GENEActiv (GENEActiv, ActivInsights Ltd., Kimbolton, Cambridgeshire, UK) (GA) on the right hip, one AG and GA on the non-dominant wrist, and one activPAL (PAL Technologies Ltd., Glasgow, UK) (AP) on the right anterior thigh (only worn during the free-living activities). The AG and GA were attached next to each other with an elastic band and the order of the monitors were counterbalanced to avoid any potential order effect. Both AG and GA monitors were set to collect raw tri-axial acceleration at 60 Hz. The AP has a sampling frequency of 10 Hz.

During free-living, the participants, or the caregivers to the children, received a diary where they recorded times when the monitors were taken off. These recordings were used to remove time when the monitors where not worn (non-wear time), and this time was not included in the analyses. The data were downloaded to a PC using the software supplied by the manufacturers (ActiLife software, version 6.5.2, GENEActiv PC Software, version 2.2 and activPAL3^{TM} Professional Research Edition software, version 7.2.29).

Raw tri-axial acceleration values from AG and GA were converted into one omnidirectional measure of body acceleration according to the method called Euclidian norm minus one (ENMO) (115). In other words, the value of gravity (1 *g*) was subtracted from the vector magnitude (VM) from the three axis, as in $\mathrm{sqrt}(x^2 + y^2 + z^2) - 1$, after which negative values were rounded up to zero. Data were further reduced by calculating the average values per one second epoch. We then calculated the average of these 1-second epoch values over the minutes included in the statistical analyses. The resulting values are expressed in milli (10^{-3}) gravity-based acceleration units (m*g*), where $1g = 9.81\ \mathrm{m/s^2}$. In **paper II**, accelerometer data were corrected for sensor calibration error by using the published auto-calibration method by van Hees and co-workers (116). Signal processing and data reduction of the raw tri-axial accelerometer data were done offline in R (https://www.cran.r-project.org/). For more details regarding the accelerometers and the data reduction, see the methods sections of **Paper I** and **II**.

Oxygen consumption - VO_2 (data only used in Paper I)

VO_2 was measured with an ergo-spirometry system with a mixing chamber (VMax Encore, SensorMedics, Netherlands) and subjects breathed through a two-way mouthpiece (2700 Series, 2-way NRBY, Hans Rudolph Inc, Kansas, USA) and wore a mask covering the nose and mouth (7450 SeriesV2 Mask ORO-NASAL, Hans Rudolph Inc, Kansas, USA). Standardised gas and flow calibration was performed before each testing. VO_2 was expressed in $mL.kg^{-1}\cdot min^{-1}$.

Anthropometry

Weight was measured in light clothing to the nearest 0.1 kg using an electronic scale (Seca, Hamburg, Germany), while height was measured without shoes to the nearest 0.1 cm using a stadiometer (Seca, Hamburg, Germany).

Statistics

Data were analysed using SPSS for Windows, version 21 (SPSS, IBM Corporations, New York, USA) and descriptive data are presented as means and standard deviations (SD). The two-tailed alpha level was set to $p<0.05$.

In both **Paper I and II** children and adults were analysed separately. Laboratory data could not be extracted from three GA monitors and therefore only 29 adults provided GA hip and wrist data, whereas 29 children provided GA hip data. In **Paper I** the tri-axial acceleration values from AG and GA and VO_2 during minutes 7.0 to 9.5 for lying and for minutes 2.5 to 4.5 for the other laboratory based activities were used in the analyses, to allow minimum 2.5 minutes to reach steady state energy expenditure for each activity. To analyse the effect of activity, brand (AG and GA), and placement (hip and wrist) and the interaction effect (activity x brand x placement) on the accelerometer output, a factorial repeated-measures ANOVA and post-hoc analyses using Bonferroni corrections were applied. If assumptions of sphericity were violated ($p<0.05$), the conservative Greenhouse–Geisser corrected values of the degrees of freedom were used. Agreement between the two brands and placement were evaluated by calculating intraclass correlation coefficient (ICC) using a two-way mixed-model ANOVA (type consistency), and the mean bias and limits of agreement between monitors were analysed with Bland–Altman plots. Linear regression analyses were performed to establish the relation between output and VO_2 from the two monitor brands and the two placements. Intensity thresholds, expressed in m*g*, for moderate (3 METs) and vigorous (6 METs) intensities were calculated from the developed regression equations. We used the conversion 1 MET=mean measured REE during lying in children (6.0 mL $O_2 \cdot kg^{-1} \cdot min^{-1}$) and adults (3.5 mL $O_2 \cdot kg^{-1} \cdot min^{-1}$), respectively. Performance of the models were assessed using a 10-fold cross-validation mode (leave-one-out cross-validation).

In **Paper II**, only 27 adults and 27 children provided adequate free-living data from all monitors, and they are included in the free-living analyses. The tri-axial acceleration values during the laboratory protocol during minutes 0.5 to 9.5 for lying and for minutes 0.5 to 4.5 for the other activities were used in the analyses. The laboratory and free-living data from the accelerometers were described in three categories, according to the APs classification groups (lie/sit, stand and step). The effect of brand, placement and the interaction effect (brand x placement) on the output during the sedentary activities in the laboratory and during free-living were examined using a two-factor repeated-measures ANOVA. Receiver operating characteristic (ROC) curve analyses were used to identify sedentary thresholds from the laboratory data for both monitors and placements in adults and children. To find the "optimal" threshold for sedentary time, sensitivity and specificity were weighted equally by using the Youden's index, which is calculated as sensitivity+specificity–1 (117). The laboratory estimates of sensitivity and specificity from the ROC-curves were cross-validated using a 10-fold cross-validation. Further, all free-living seconds that had a corresponding accelerometer output lower than the developed thresholds were coded as sedentary, and all other seconds were coded as non-sedentary time. The agreement between accelerometer time coded as sedentary and sedentary time measured by the AP was examined using paired t-tests. The accuracy of the developed thresholds during free-living was examined by calculating the percentage amount of time correctly classified as sedentary (sensitivity) and as not sedentary (specificity). Bland-Altman plots were used to assess the individual mean bias and the limits of agreement between free-living time spent sedentary from the laboratory derived thresholds and AP.

Examination of the association between birth weight and sedentary time, and whether it is mediated by central adiposity (Paper III)

Participants

In the second study (**Paper III**) we used data from ICAD, which consists of re-analysed and pooled accelerometer data combined with phenotypic information from observational studies in youth aged 3–18 years (n=~32,000). The aims, design, inclusion criteria and methods of the ICAD project have been described in detail previously (118). In the present study, data from eight studies conducted between 1997 and 2007 in Europe (n=7) and Brazil (n=1), in which measured or maternally reported birth weight, measured waist circumference and sedentary time were available, were included (n=10,793, boys: 47%). This sub-sample (aged 6-18 years) differed slightly from the whole ICAD sample in terms of time spent sedentary (+16 min/d; 4.3%, p<0.001) and waist circumference (+1 cm; 1.5%, p<0.001). Ethical approval was granted for each individual study, and all participants have provided informed parental consent. In addition, formal data-sharing agreements were established, and all partners consulted with their individual research boards to confirm sufficient ethical approval had been attained for contributing data to ICAD.

Measurements

Accelerometry

ICAD accelerometer data were re-analysed centrally in a standardised manner with customised software (KineSoft Software, version 3.3.20; Kinesoft.org) and processed in 60-second epochs to provide comparable physical activity outcomes across studies (118). The Pelotas study used a 24-hour wear protocol, whereas the other studies asked participants to wear the accelerometer during waking hours only. To avoid accelerometer data being influenced by the increased wear time, accelerometry data were excluded for the overnight period between 24.00 and 07.00 in the Pelotas study. Children with minimum of three days with at least 600 minutes of measured monitor wear time between 07.00 and midnight were included. Non-wear time was defined as 60 minutes of consecutive zeroes, with the allowance for 2 minutes of nonzero interruptions, terminated at the third nonzero interruption (119, 120). Overall physical activity was calculated as total counts over the wear period and expressed in cpm. Time spent sedentary was defined as all minutes with <100 cpm (121), whereas time spent in MVPA was defined as minutes with >3000 cpm (72). Both sedentary time and time spent in MVPA are expressed in minutes per day.

Anthropometry

Birth weight was directly measured (Pelotas study) or maternally reported. Waist circumference was used as a surrogate measure for abdominal adiposity and measured using a metal anthropometric tape midway between the lower rib margin and iliac crest at the end of a gentle expiration. Height and weight were measured by using a standardised procedure across studies. Body mass index, BMI (weight divided by height squared,) was calculated for each participant, and age- and sex specific BMI cut-offs were used to categorise participants as normal weight, overweight, or obese (122).

Statistics

Data were analysed using SPSS for Windows, version 21 (SPSS, IBM Corporations, New York, USA) and descriptive data are presented as means and standard deviations (SD). The two-tailed alpha level was set to $p<0.05$.

In order to assess whether waist circumference (cm) acts as a potential mediator of the association between birth weight (kg) and sedentary time (minutes/day), we used the resampling strategies and the macro presented by Preacher and Hayes (123). Bootstrapping is a non-parametric resampling procedure, and the method involves repeated sampling from the data set, and the indirect effect is estimated in each resampled data set. In the unstandardised regression equation (ordinary least squares regression), birth weight was modelled as the predictor, sedentary time as the outcome, waist circumference as the mediator and sex, age, study and monitor wear time as covariates. The analyses were used to determine the total (c path) and direct effect (c' path) of birth weight on sedentary time, and to estimate the mediating role of waist circumference (the a x b products, indirect effect of the independent variable on the dependent variable through the mediator) (Figure 1). In the present study, a 95% bias-corrected confidence interval (bCI) for each a x b product was obtained with 5,000 bootstrap resamples and was used to assess whether waist circumference mediated the association between birth weight and sedentary time. A significant indirect effect via the mediator between birth weight and sedentary time was determined if the 95% bCI did not overlap zero. Since we did not have data on gestational age, we performed sensitivity analyses excluding participants with birth weight <2.5 kg (n=553). We examined whether the association between birth weight and sedentary time was modified by sex or age by including the interaction term birth weight x sex, and birth weight x age, however no significant interactions were observed ($p>0.10$). The association between different categories of birth weights and sedentary time is displayed graphically for illustrative purpose and presented as means and 95% CI of sedentary time for each birth weight group. Birth weight was divided into six categories: <2.75 (n=1,164), 2.75-3.25 (n=2,822), 3.26-3.75 (n=4,160), 3.76-4.25 (n=2,117), 4.26-4.75 (n=449) and >4.75 kg (n=81) and the birth weight category 3.26-3.75 kg was chosen as the reference category as it contained the largest proportion of participants, and in agreement with previous studies (124).

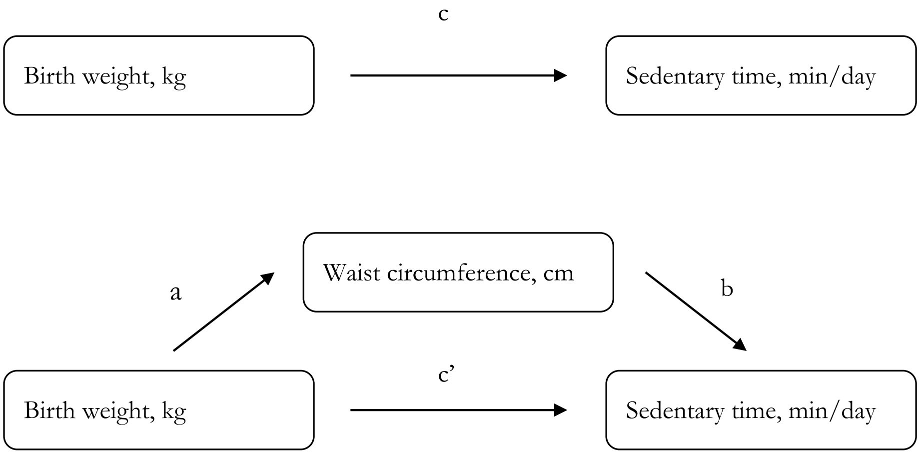

Figure 1. *Conceptual mediation analysis.*

Step b adjusted for the independent variable, while step c' is adjusted for the mediator.

Systematic review - search protocol (Paper IV)

The systematic review aimed to identify all observational (non-intervention) longitudinal studies (prospective and retrospective) reporting data on the association between one or more of the potential predictors and sedentary behaviour in young people (aged ≤18 years). This review is registered in the International Prospective Register of Systematic Reviews (PROSPERO, CRD42014014156) and follows the PRISMA guidelines. Ethics committees in the respective countries have approved the included studies and the participants have given their consent to participate.

Study inclusion criteria

Only studies that examined factors which may be casually associated with the outcome, rather than correlates (factors which are statistically associated with the outcome in cross-sectional analyses), were included. The term "determinant" is often used in similar studies (95, 96), however since evidence from observational studies does not prove cause-and-effect relationship (125), we here use the term "predictor".

The following inclusion criterias were used: (i) written in English (ii) published after 01/01/2000; (iii) published as journal articles or reports; and (iv) including healthy children. The potential predictors were identified as prenatal, birth and early life characteristics, previously classified under the physical domain (126, 127) when studied in relation to physical activity (128, 129). Early life was defined as from birth to three years of age. Early motor development up to three years of age is characterised by achieving fundamental developmental milestones, e.g. sit with and without support, supported and unsupported standing and walking (130). Early life temperament refers to biologically based individual differences in emotional, motor and attentional reactivity (131). When considering growth and body size (body weight/fat mass/body mass index, BMI) studies examining these factors between birth and 6 years of age were included, to take into account potentially critical periods such as the adiposity rebound (132). In addition, gene variants may influence on the in utero development (113), and was therefore explored as a potential predictor.

Sedentary behaviour includes activities such as watching TV, using a computer or sitting at school. Studies were included if they measured total sedentary time (e.g. minutes/day) or a specific type of sedentary behaviour (e.g. TV-viewing, computer use etc.), measured either objectively (e.g. with an accelerometer) or subjectively (e.g. with self- or parentally reported questionnaires).

Search strategy

Two researchers performed a systematic literature search in the electronic databases PubMed, SPORTDiscus, EMBASE and Web of Science including studies published between January 2000 and December 1, 2015. The searches included terms related to sedentary behaviour in combination with the sample of interest and terms related to the potential predictors.

Identified articles were imported to Reference Manager Professional Edition (version 12, Thomson Reuters, San Francisco, CA, USA) and duplicates were removed. One researcher screened the titles, whereas two researchers independently screened all abstracts to minimize the risk of elimination of eligible studies by mistake. If any doubts, the articles were included to the next phase. Two researchers independently performed the full-text review. The reference lists of all included studies were reviewed (backward tracking), and a citation search was performed in the database Web of Science (forward tracking).

Quality assessment

Quality assessment of the included studies was performed using a formal checklist (133). Two independent researchers performed the quality assessment, and any disagreements were resolved by consensus or by consultation with a third researcher if necessary. Study quality scores range from 0-1, where a higher score corresponds to higher quality. The result of the quality assessment was used for discussion of the quality of the studies and no study was excluded based on this assessment.

Data extraction and statistics

Data were extracted using standardised forms independently by two researchers, and any disagreements were resolved by consensus or by a third researcher. Researchers were not blinded to the authors or journals when extracting data.

The primary aim was to synthesise the evidence by formal meta-analyses on the association between the predictors and sedentary behaviour. However, due to few studies retrieved and heterogeneity in the exposure and outcome measures in these studies, this was not possible. Therefore, the data were synthesised narratively.

Results and discussion

The following section summarises the main findings of **Paper I-IV**. For details, the reader is referred to the original papers (included at the end of the thesis).

Age group comparability of raw accelerometer output from wrist- and hip-worn monitors (Paper I)

Table 1. *Mean (SD) descriptive characteristics for children and adults.*

	Adults (n=30)	**Children (n=30)**
Girls, n (%)	17 (56.7)	14 (46.7)
Age, y	34.2 (10.7)	8.9 (0.9)
Height, cm	174.2 (8.4)	136.5 (8.9)
Weight, kg	73.3 (13.1)	31.1 (6.2)
BMI, $\text{kg}^{-1}\text{m}^{2}$	24.1 (3.7)	16.6 (1.8)
Free-living data (minutes) (only Paper II)		
Wear time	904 (88)	791 (172)
Sedentary time	485 (131)	392 (121)
Standing time	279 (137)	242 (86)
Stepping time	139 (62)	156 (60)

Descriptive data for children and adults are shown in Table 1, and accelerometer output during the activities are shown in Table 2. In general, increase in intensity (VO_2) corresponded to an increase of accelerometer output (m*g*) from both AG and GA at both placements. In both children and adults, a factorial ANOVA showed a significant effect of activity ($F_{(2.1, 47.9)}=355.2$; $F_{(1.3, 35.5)}=1031.7$; $p<0.0001$) and placement ($F_{(1.0, 23.0)}=31.7$; $F_{(1.0, 27.0)}=83.3$; $p<0.0001$), with significantly higher output from the wrist monitors than the hip monitors ($p<0.001$). A significant interaction effect of activity x placement on the acceleration values was observed in both groups ($F_{(1.5, 35.2)}=36.6$; $F_{(1.2, 32.7)}=79.7$; $p<0.0001$). Compared with the output from the monitors on the hip, the output from the wrist monitors were higher during the more intense activities, but similar or lower during the sedentary activities, including lying and sitting. No significant main effect of brand was observed in children and adults (p=0.73 and 0.12, respectively). A significant three-way interaction effect (activity x placement x brand) was observed in children ($F_{(2.0,\ 46.5)}$=8.2, p=0.001). Post hoc analyses per activity showed a significant interaction between placement x brand during four activities, suggesting that the accelerometer output between the two brands placed at the hip or the wrist are comparable for some but not all of the studied activities in children. In adults, no significant three-way interaction was observed (p=0.49).

Table 2. *Mean (SD) accelerometer output from AG and GA (mg) and* VO_2 *(mL·kg*$^{-1}$*·min*$^{-1}$*) during each activity performed by adults and children.*

		Lying quietly	**Sitting**	**Standing**	**Circuit**	**Slow walk 3 km/h**	**Fast walk 5 km/h**	**Step**	**Running 8 km/h**
Adults (n=30)	AG hip	2.22 (6.25)	4.41 (8.47)	9.75 (13.17)	24.93 (22.62)	69.80 (20.67)	156.65 (23.35)	70.12 (34.74)	465.89 (75.21)
	GA hip^1	2.86 (6.20)	1.90 (3.48)	14.23 (55.48)	19.15 (25.06)	69.10 (26.29)	156.25 (26.52)	69.87 (39.29)	475.96 (76.92)
	AG wrist	7.16 (10.89)	11.78 (23.45)	22.11 (28.46)	71.84 (64.78)	81.88 (35.91)	177.22 (63.52)	91.94 (49.33)	765.03 (202.77)
	GA wrist^1	0.31 (1.34)	4.31 (11.94)	9.08 (15.71)	65.34 (63.75)	72.90 (28.87)	169.80 (56.25)	85.67 (46.31)	761.30 (200.29)
	VO_2	3.5 (0.5)	3.7 (0.8)	3.9 (0.9)	8.9 (2.3)	8.7 (1.3)	11.8 (1.2)	13.0 (2.2)	26.1(2.9)
Children (n=30)	AG hip	5.56 (12.38)	10.51 (13.85)	18.41 (17.52)	29.50 (26.09)	91.66 (28.26)	194.55 (41.75)	149.60 (196.89)	534.71 (84.69)^2
	GA hip^1	14.28 (18.49)	7.65 (19.18)	14.02 (29.63)	26.48 (36.21)	91.80 (32.31)	199.75 (47.24)	158.28 (223.25)	589.89 (114.46)^2
	AG wrist	8.37 (22.75)	14.66 (26.72)	33.03 (42.15)	74.73 (77.25)	100.60 (53.72)	219.00 (99.42)	168.90 (202.73)	817.15 (235.40)^2
	GA wrist	2.32 (10.56)	3.83 (12.08)	21.37 (37.09)	65.33 (80.27)	89.38 (47.30)	206.64 (88.24)	156.84 (210.56)	809.10 (231.14)^2
	VO_2	6.0 (1.0)	6.4 (1.2)	6.7 (1.7)	10.6 (2.4)	12.8 (1.9)	17.0 (2.1)	19.8 (6.9)	33.0 (3.0)^2

$^1n=29$, $^2=24$

Figure 2 displays Bland-Altman plots showing the mean bias and 95% limits of agreement between AG and GA placed at the hip in adults (Fig. a) and children (Fig b) and for the wrist placement in adults (Fig. c) and in children (Fig d). A significant negative correlation was observed between average acceleration values and difference in values from the hip placed monitors in both adults (-0.16, p=0.013) and in children (-0.55, p<0.0001), which was most pronounced during higher acceleration values. ICC between different brands for adults and children ranged between 0.96-0.99, while ICC between different placements for adults and children ranged between 0.90-0.92.

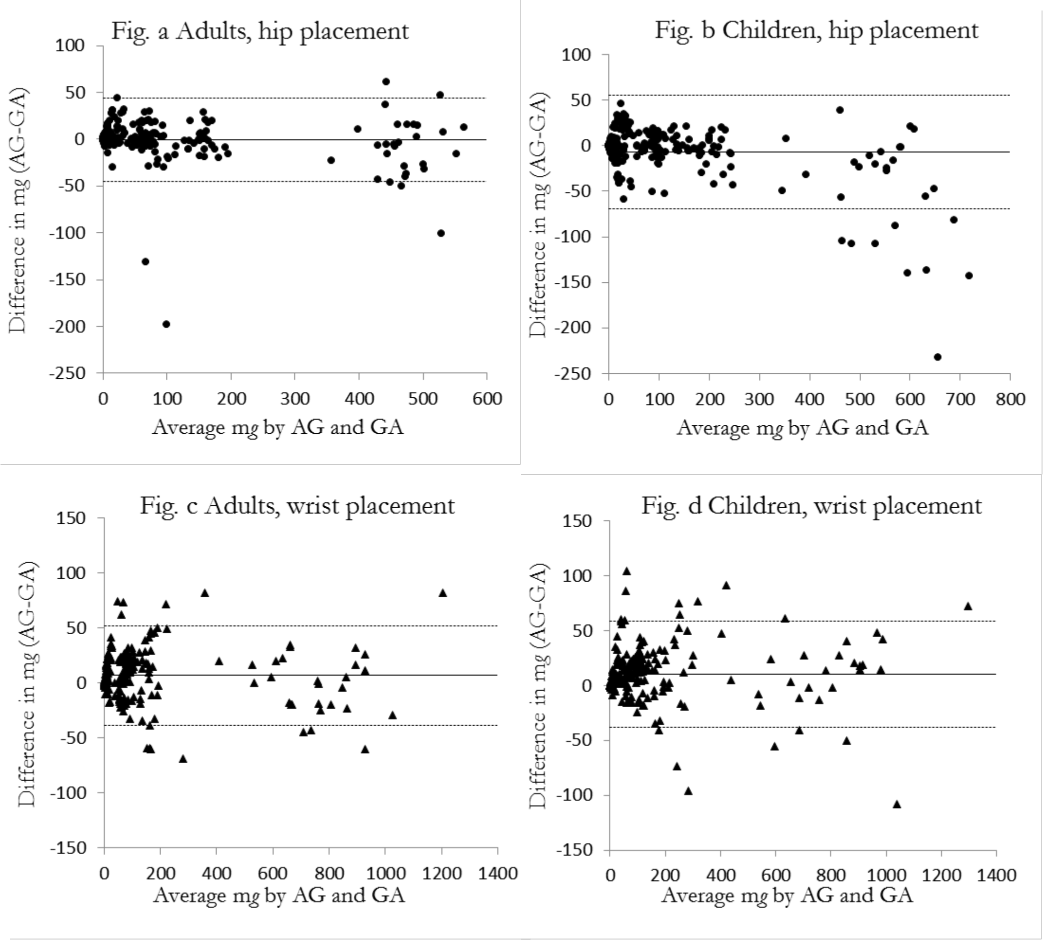

Figure 2. *Bland-Altman plots assessing the agreement between output (mg) from the two monitors placed at the hip and the wrist for adults and children separately. Dotted lines represent 95% limits of agreement (±1.96SD).*

It was not a clear pattern in the differences in acceleration values between the two brands and placements and I can only speculate why the output from the monitors varies and why it is greater in children. There are several technical factors that influence the signal output by the MEMS sensor, including bandwidth, filter strategy, sampling rate, dynamic range, sensitivity, signal noise and data resolution. The MEMS sensor differs between the two accelerometer brands: The GA uses the Analog Devices ADXL345, while AG uses the Kionix® (Ithaca, NY, USA) KXSC7-3672 accelerometer. GA uses no filtering of the raw data, while AG applies filtering but decides to keep the details of this filtering process proprietary (134). Finally, consistent and accurate attachment of accelerometers in children is more challenging due to their smaller body size. Although the absolute distance between the two accelerometer brands might be the same, the relative difference (relative to rotating body) is greater in children, which may explain a greater difference in monitor output.

The developed intensity thresholds for moderate (3 METs) and vigorous physical activity (6 METs) are shown in Table 3. Interestingly, the derived intensity thresholds were remarkably similar between monitor brands placed at the hip (<3% difference) and the wrist (<8% difference) respectively, possibly with the exception for the hip placement in children (7-11% difference). The 10-fold cross-validation of the intensity thresholds suggests that sedentary/light (93-97%) and vigorous activities (68-92%) were accurately classified most of the time from both monitors at both locations, while the moderate intensity activities, for example stepping and circuit, showed lower accuracy (33-59%), especially in children.

Table 3. *Intensity thresholds for moderate and vigorous physical activity in children and adults.*

		Moderate intensity (m*g*)	**Vigorous intensity (m*g*)**
Adults	AG hip	69.1	258.7
	GA hip	68.7	266.8
	AG wrist	100.6	428.8
	GA wrist	93.2	418.3
Children	AG hip	142.6	464.6
	GA hip	152.8	514.3
	AG wrist	201.4	707.0
	GA wrist	191.6	695.8

Since this is the first study to report intensity thresholds for AG and GA expressed in *g*, it is not possible to compare our results with those from previous studies. However, two studies have derived intensity thresholds for a similar device (GENEA) and in agreement with our observations they reported higher intensity threshold values for the wrist placement compared to the hip placement (135, 136). Nevertheless, a direct comparison of the results with the present study is not possible. First, it is unsure if the accelerometer output from these different monitors (GENEA versus GA versus AG) are directly comparable. Second, the two previous studies used another approach for data reduction. In the present study, negative values resulting from subtracting the VM by one *g* were replaced by zero, while in the studies by Esliger and co-workers (135) and Phillips and co-workers (136) the negative values were replaced by their absolute value. Negative values are potentially a result from calibration error and not related to body movement, which is why rounding them to zero appears preferable. It is also acknowledged that downward accelerations may cause negative VM values. However, taking the absolute of a negative value will only correct for these negative accelerations in the lower acceleration range and therefore introduce non-linearity into the overall range in VM values, suggesting rounding negative acceleration values to zero may be preferable. Next, the resulting values in the previous studies were summed per second rather than averaged per second (135, 136). Summing the resulting values may introduce an undesirable dependency on sample frequency complicating comparison of results across studies based on different sample frequencies. The use of the average *g* means that the intensity thresholds derived in present study could be used irrespective of sampling frequency or epoch length, hence facilitating easy comparisons across studies. However, it should be noted that a longer epoch length is associated with an increased chance for capturing multiple activity types or multiple intensities within an epoch. This may then blur the average acceleration and make data harder to interpret. Finally, our results are expressed in *g* while the other values were expressed in *g* seconds.

Methodological issues

The present study has a number of strengths. First, similar to previous studies (137, 138), a variety of common daily activities not only restricted to treadmill activities, were included when establishing the relationship between acceleration and VO_2 in order to mimic free-living activities. Furthermore, both children and adult spend most of their time being sedentary (139, 140) and a strength of the current study is that the protocol included sedentary activities like lying and sitting. Finally, VO_2 was assessed by indirect calorimetry, which is considered as a valid method for energy expenditure measurements, and REE was measured individually in all participants. However, there are also a number of limitations that warrant consideration. The sample was a convenient sample consisting of healthy children and adults, consisted of only two age groups and did not include obese individuals. The study only included indoor activities, and the selection of activities in any calibration protocol will probably alter the association between acceleration values and VO_2, hence the derived intensity thresholds from this study may only be valid for the activities performed. However, sitting, standing and locomotion at different speeds likely contribute to the vast majority of waking hours in most individuals. Finally, it has been suggested that the single-regression equations developed to calculate intensity thresholds are not able to accurately predict time spent in different intensities across a wide range of activities (68, 141). Alternatively, other methods for analysing output from accelerometers are likely to improve the estimation of intensity from acceleration values (142, 143).

Development of sedentary thresholds and free-living agreement with activPAL (Paper II)

Descriptive data for children and adults are shown in Table 1, while Table 4 shows the mean accelerometer output, in APs three categories during the activities performed in the laboratory, and free-living, for children and adults, respectively. During sedentary activities in the laboratory, a two-factor repeated-measures ANOVA showed a significant main effect of brand and placement in adults ($F_{(1, 21565)}=35$, $F_{(1, 21565)}=1105$, $p<.0001$) and children ($F_{(1, 15313)}=4$, $F_{(1, 15313)}=4680$, $p<.05$). A significant interaction effect between brand x placement was found in both adults ($F_{(1, 21565)}=904$, $p<.0001$) and children ($F_{(1, 15313)}=576$, $p<.0001$), indicating that the brand had different effects on the output depending on the placement. During free-living sedentary activities, the ANOVA showed a significant main effect of brand and placement in adults ($F_{(1, 727973)}=2768$, $F_{(1, 727973)}=85073$, $p<.0001$) and children ($F_{(1, 580362)}=4446$, $F_{(1, 580362)}=38225$, $p<.0001$), as well as a significant interaction effect (adults, $F_{(1, 727973)}=3390$; children, $F_{(1, 580362)}=7125$, $p<.0001$). In both adults and children, the output from the GA monitors were significantly higher compared to the AG monitors when placed on the hip ($p<.0001$), but lower when place on the wrist (only significant for children, $p<.0001$).

Table 4. *Accelerometer output (mean (SD)) from ActiGraph (AG) and GENEActiv (GA), expressed in mg, in the three categories defined by the activPAL during laboratory and free-living activities by adults and children.*

		Sedentary activities		**Standing**		**Stepping activities**	
		Laboratory	**Free-living^2**	**Laboratory**	**Free-living^2**	**Laboratory^3**	**Free-living^2**
Adults (n=30)	AG hip	12.5 (18.1)	7.9 (19.9)	26.0 (30.2)	24.7 (44.8)	240.5 (174.4)	110.8 (140.5)
	GA hip^1	15.8 (18.0)	11.0 (28.7)	9.3 (19.4)	28.1 (54.6)	230.5 (176.9)	117.0 (146.2)
	AG wrist	11.5 (15.0)	21.6 (45.5)	9.1 (16.5)	59.0 (93.6)	329.7 (313.5)	179.3 (234.0)
	GA wrist^1	9.6 (14.0)	21.5 (45.7)	25.1 (33.4)	56.7 (99.9)	354.8 (328.8)	191.2 (274.9)
Children (n=30)	AG hip	18.7 (25.3)	18.1 (43.9)	36.6 (41.0)	41.8 (81.1)	249.1 (182.9)	101.3 (138.6)
	GA hip^1	14.7 (17.5)	30.4 (54.4)	17.3 (29.2)	52.0 (85.2	245.3 (196.6)	110.8 (145.9)
	AG wrist	8.4 (13.4)	43.7 (109.5)	22.2 (35.1)	88.8 (199.3)	294.5 (291.4)	195.0 (345.2)
	GA wrist	12.0 (18.9)	43.4 (114.9)	34.1 (41.4)	88.9 (208.5)	326.2 (311.5)	195.0 (338.9)

^{1}*n=29;* ^{2}*n=27;* ^{3}*Inluding slow and fast walking, and running.*

Development of sedentary thresholds using laboratory data

Table 5 shows the results from the ROC analyses used to develop the sedentary thresholds. In general, the corresponding sedentary thresholds were 1) higher for the hip than the wrist, and 2) similar for the two brands at the same placement, except in children for the wrist monitors (35.6 versus 56.3 m*g*). Overall, the classification accuracy was similar for wrist and hip thresholds. The sensitivity was almost perfect for all developed thresholds ranging from 93-100%, however this was accompanied by reduced specificity ranging from 68 to 78%. The 10-fold cross-validation showed a small reduction in sensitivity (88-96%), and similar or a small increase in specificity (71-78%).

Table 5. *Sensitivity, specificity and Area under the receiver operating characteristic curves (AUC), in addition to proposed thresholds for ActiGraph (AG) and GENEActiv (GA) worn at the hip and wrist for children and adults separately.*

		Sensitivity (%)	**Specificity (%)**	**AUC**	**Threshold (*m*g)**
Adults	AG hip	96	78	0.92, p<0.001	47.4
(n=30)	GA hip[1]	93	73	0.84, p=0.002	46.9
	AG wrist	98	74	0.87, p=0.002	44.8
	GA wrist[1]	98	78	0.92, p<0.001	45.8
Children	AG hip	93	77	0.89, p=0.002	63.3
(n=30)	GA hip[1]	100	68	0.87, p=0.002	64.1
	AG wrist	98	74	0.91, p<0.001	35.6
	GA wrist	97	75	0.91, p=0.002	56.3

[1] *n=29*

The specificity values for the developed thresholds were lower compared to earlier studies that have developed sedentary thresholds using raw tri-axial laboratory data and ROC analyses for the GA worn at the wrist (144) or a similar device (GENEA) worn at the wrist and hip (135, 136). For example, the developed GA wrist threshold in children had a specificity value of 75%, while a specificity value of 97% has been reported in other studies (136). The lower specificity values may partly be explained by the inclusion of a standing activity in the laboratory protocol, since the magnitude of acceleration while standing correspond to the magnitude of acceleration when sedentary. By excluding the standing activity from the ROC analyses, the specificity for the GA wrist threshold in children increased from 75 to 93% (without affecting the sensitivity, or the threshold value), which is a more similar value compared to other studies. Another difference compared to earlier studies (135, 136, 145), is that the developed wrist sedentary thresholds were 5-44% (2.6-28.5 m*g*) lower than the hip thresholds in both children and adults. This may be due to the placement of the wrist monitors on the non-dominant hand, which exclude recordings of extra but inessential movements that may occur by the dominant hand. Also, differences in thresholds may partly be due to different data reduction methods between our and previous studies, discussed previously (146).

Free-living measurement period

The developed thresholds ability to measure free-living sedentary time compared to AP was low regardless of placement and in both age groups. When examining absolute agreement, i.e. the amount of time correctly classified as sedentary or non-sedentary by both AP and the developed thresholds, the AG wrist threshold in adults had the highest sensitivity (87%) and specificity (49%), while the sensitivity and specificity for the other developed thresholds ranged from 68-97% and 26-59% respectively. There are several possible reasons for why the specificity (i.e. the thresholds ability to classify non-sedentary activities correctly) during free-living was low. The AP was used as the reference measure for free-living sedentary time. Even if this monitor has been validated for measuring sedentary time in both children (42, 43) and adults (45, 47) the device has some limitations. First, when comparing the developed thresholds with AP, I am comparing acceleration, or lack of acceleration, with body posture, and it is likely that these two measures are not perfectly compatible since a person can stand without moving and lie/sit while moving. An accelerometer can not discriminate between sedentary activities and non-sedentary activities if no movement is occurring at the body segment where the monitor is attached, and this is most likely the main disadvantage with using a single accelerometer to capture sedentary activities. Second, postural misclassification of sitting as standing by the AP (43) may result in an underestimation of sedentary time determined by the AP, and contribute to the low specificity for all developed thresholds during free-living. Third, many daily activities are complex and consists of other movements than those captured by three standardized postures detected by the AP, for example squatting and kneeling, which may be especially relevant when measuring posture in children. Consequently, time spent in non-standard positions may potentially cause a substantial challenge when measuring free-living postures in children over a prolonged time, like in the present study. Finally, another possible explanation why the developed thresholds have limited accuracy during free-living could be the low number of activities included in the laboratory protocol, possibly leading to a limited spectrum of movements compared to free-living activities.

In general, compared to AP, the wrist thresholds performed somewhat better than the hip thresholds, and this may be an important implication for population studies, since wrist mounted monitors may increase compliance and less loss of data (147). According to the criterion AP, adults spent on average 54% (485±131 min) of the free-living measurement period sedentary. The corresponding estimates of sedentary time using the developed thresholds were all significantly higher ($p<0.001$); AG hip, 86% (779±87 min); AG wrist, 69% (628±93 min); GA hip, 84% (762±106 min); and GA wrist, 72% (651±81 min). Children spent on average 50% (392±121 min) of the free-living measurement period sedentary according to the AP. The corresponding estimates of sedentary time from the AG wrist threshold was 53% (423±145 min), and this was not significantly different from AP ($p=0.3$). The other thresholds significantly overestimated mean sedentary time ($p<0.001$); AG hip, 82% (652±157 min); GA hip, 76% (604±181 min); and GA wrist, 65% (513±155 min).

Figure 3 shows Bland-Altman plots for the mean individual bias and 95% limits of agreement between sedentary time from the AP and the developed thresholds from AG hip (Fig. a), GA hip (Fig. b), AG wrist (Fig. c) and GA wrist (Fig. d) for adults and children respectively. Overall, the AG wrist threshold in children performed the best, with a small mean individual bias (+11%). Nevertheless, even if the mean bias was small, the 95% limits of agreement in Bland-Altman plots were wide, ranging from +76 (287 min) to -54% (-226 min) of sedentary time compared to AP. Hence, the AG wrist threshold in children might be sufficiently accurate to assess sedentary time in a surveillance study focusing on data on the population level, however, the wide limits of agreement suggests that it is not possible to accurately determine the amount of time spent sedentary in individuals. Therefore, it is uncertain whether the developed thresholds can be used to detect small, but potentially important, associations between for example individual sedentary time and different health outcomes. Further, in opposite to the observations in children, a significant negative correlation ($r=-0.5$ to -0.6, $p<0.01$) was observed between average sedentary minutes and mean bias for all thresholds in adults, suggesting a systematic error. However, due to the small number of participants ($n=30$), these results should be interpreted cautiously.

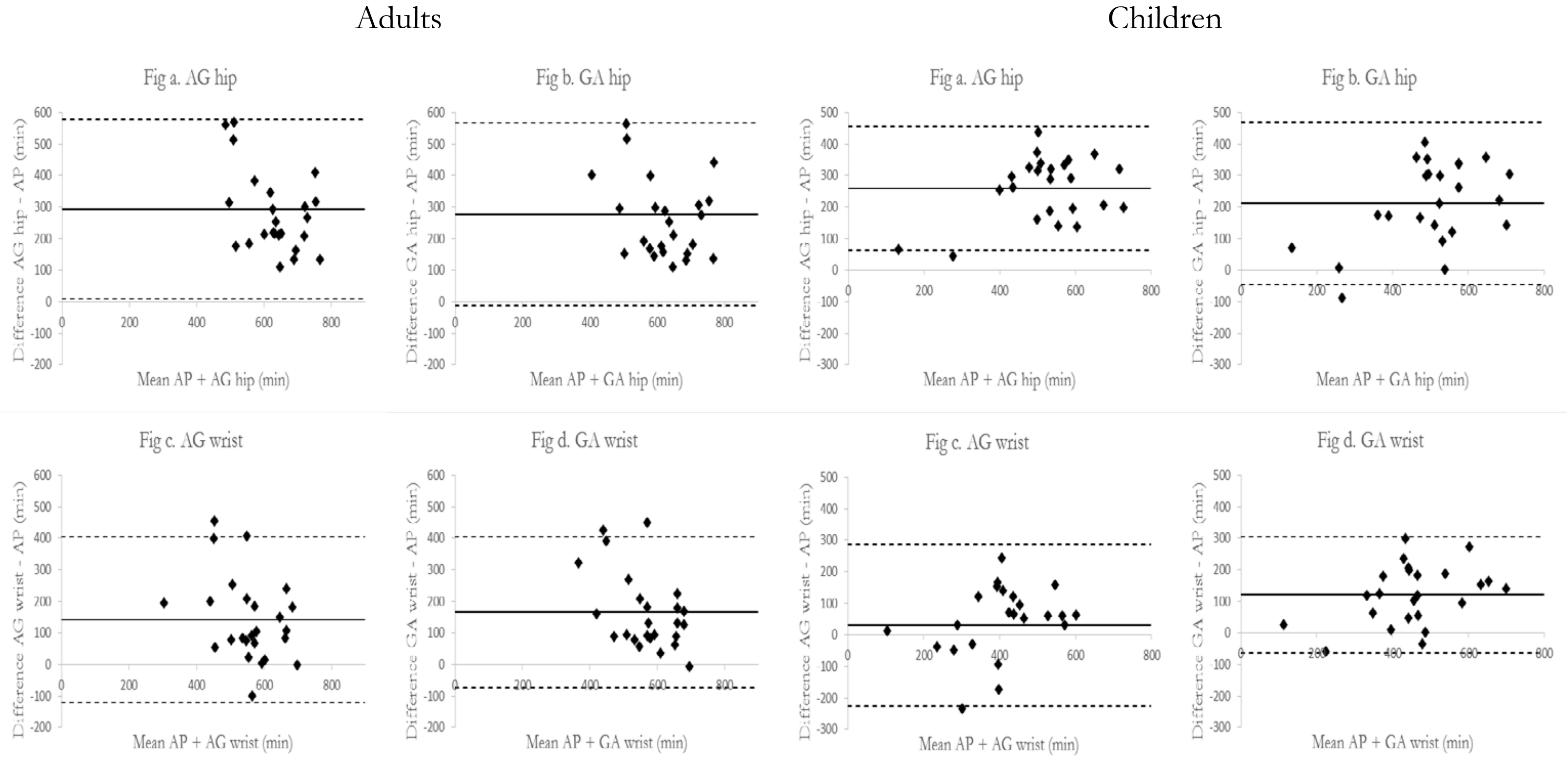

Figure 3. *Bland-Altman plots assessing the agreement between sedentary time (minutes) from the activPAL (AP) and sedentary time from the ActiGraph (AG) and GENEActiv (GA) placed at the hip and wrist in adults and children respectively. Mean bias is represented by a solid line; 95% limits of agreement with dotted lines.*

I can only speculate why the wrist thresholds in children were dissimilar (35.6 versus 56.3 m*g*), despite similar accuracy in the ROC analyses (AUC=0.91). Even if precise attachment of accelerometers in children may be more challenging, the monitors were attached equally tightly next to each other and the order of the monitors were counterbalanced to avoid any potential order effect. Thus, it is unlikely that this explains the difference in thresholds. Another possible explanation for the poorer consistency for children may be the auto-calibration procedure, which relies on the detection of non-movement periods. This method is validated in adults over multiples days (116), however not in children. Children often engage in sedentary bouts lasting for about 5 minutes or less (148). Thus, the number of non-movement periods may be low and consequently, the quality of the sensor calibration less optimal for the wrist placement in children. When replicating the analyses using the lower (35.6 m*g*) AG threshold on the GA free-living data in children, the results from the two brands were similar suggesting results for estimating time spent sedentary from the two monitors are comparable when applying the same threshold. These results also suggest that intensity thresholds defined as an exact value developed from ROC analyses based on a few activities performed in the laboratory are prone to misclassification.

Even if the newer versions of accelerometers enables data from multiple axis to be expressed in gravity based units, most studies using accelerometers still expresses their data in counts from one single axis (28, 32, 91), and <100 cpm is often used as a threshold for sedentary time. Several studies have shown that this threshold is valid for estimating sedentary time in controlled environments and during free-living activities in children and adults (46, 72, 75, 149). The relative performance of this threshold appears better than our developed thresholds, especially during free-living.

Methodological issues

There are several ways to define the "optimal" threshold when using ROC-curves, for example by using the Youden's Index or the point on the ROC curve closest to (0,1). However, there is no consensus on which measure to use when defining optimal thresholds for physical activity and sedentary time, i.e. there exists no "generally optimal" threshold, and the "optimal" thresholds depends on the conditions. Thus, when trying to define the "optimal" threshold for sedentary time, I believe that sensitivity and specificity should both be maximized suggeting the use of the Youden's Index, but the use of another approach may have resulted in different thresholds. Lastly, comparing raw tri-axial accelerometer data in **Paper I** (Table 2) and **II** (Table 4) during the laboratory protocol shows some differences. Some variation in output was expected since more time (seconds) were used in the analyses in **Paper II** than **Paper I**. However, these differences are most likely a result of the different ways the data was processed. Van Hees and co-workers (116) showed that their auto-calibration method, which relies on the detection of non-movement periods, can have a significant impact on ENMO values, especially in the lower acceleration range. Therefore, I choose to correct for sensor calibration in **Paper II,** however this was not done in **Paper I** since this work was not published. These differences in values highlight the need of a standardized protocol to process raw accelerometer data so that data are actually comparable.

Examination of the association between birth weight and sedentary time, and whether it is mediated by central adiposity (Paper III)

Descriptive statistics by gender are summarised in Tables 6. Overall, 79.3% of the children were categorised as normal weight, 15.9% as overweight and 4.8% as obese. Children's sedentary time and physical activity were monitored for an average of 5.3 (1.3) days. Overall, average time spent sedentary was 370 (91) minutes per day, while on average 56 (30) minutes per day were spent in MVPA.

Table 6. *Baseline descriptive (mean ± SD) of the sample stratified by sex (n=10,793)*

	Boys (n=5,092)	**Girls (n=5,701)**	**p value[1]**
Age, years	11.5 ± 1.6	11.5 ± 1.7	0.63
Weight, kg	42.0 ± 12.1	42.8 ± 11.6	**0.001**
Height, cm	149.1 ± 11.9	148.8 ± 10.7	0.13
Waist circumference, cm	66.7 ± 9.2	65.7 ± 9.2	**<0.001**
BMI[2]	18.6 ± 3.2	19.0 ± 3.4	**<0.001**
Normal weight[2], n (%)	4109 (80.8)	4432 (77.9)	
Overweight[2], n (%)	767 (15.1)	946 (16.6)	
Obese[2], n (%)	207 (4.1)	312 (5.5)	
Birth weight, g	3459 ± 584	3345 ± 535	**<0.001**
Total physical activity, cpm	637 ± 231	528 ± 186	**<0.001**
Sedentary time[3], min/day	360 ± 91	380 ± 90	**<0.001**
MVPA[3], min/day	66 ± 33	46 ± 23	**<0.001**
Wear time, day	5.4 ± 1.4	5.3 ± 1.3	0.96

[1]p values denotes statistical differences between gender; [2]n for boys and girls is 5,083 and 5,690 respectively. The age- and gender specific BMI cut off points proposed by Cole and co-workers (122) were used; [3]Cut points for sedentary time and MVPA is 100 and 3000 cpm respectively.

Figure 4 shows the separate regression analyses conducted to assess each component of the proposed mediation model among variables. Birth weight was associated with sedentary time and a 1 kg increase in birth weight was associated with four more minutes spent sedentary per day (c path; B=4.04, p=0.006). This association seemed to be mainly driven by individuals in the extreme categories of birth weight (<2.75 kg and >4.75 kg). In addition, birth weight was positively associated with waist circumference (a path; B=1.59, p<0.001) and waist circumference was positively associated with sedentary time (b path; B=0.82, p<0.001). The results of the mediation analysis confirmed the mediating role of waist circumference in the association between birth weight and sedentary time (a x b path; B=1.30, 95%bCI=0.94, 1.72). Furthermore, our results showed that the direct effect of birth weight on sedentary time was attenuated with 32 % (c' path; B=2.74, p=0.06) when controlling for waist circumference, hence suggesting partial mediation. In sensitivity analyses, excluding individuals with a birth weight <2.5 kg, the results were mainly unchanged, and supports a partial mediating role of waist circumference (a x b path; B=1.74, 95%BCI=1.26, 2.30).

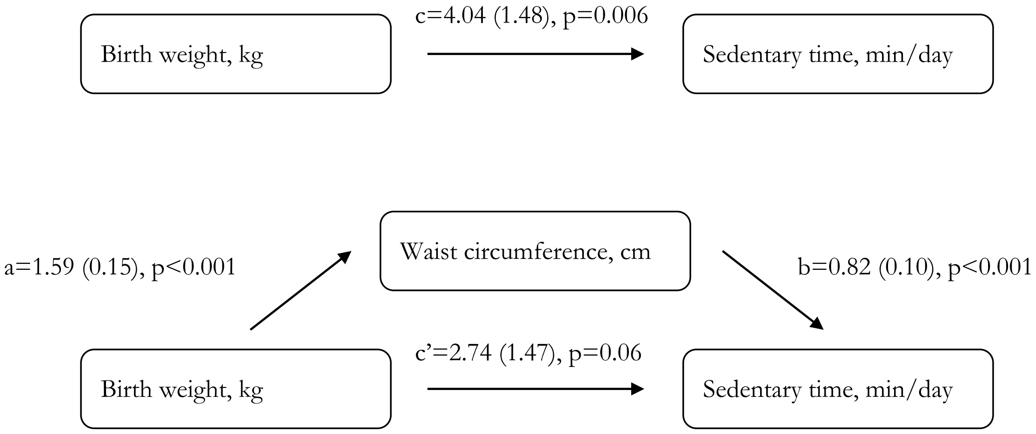

Figure 4. *The unstandardised regression coefficients (SE) in the regression analyses included in the mediator model between birth weight, waist circumference and sedentary time (n=10,793).*

The results support that the association between birth weight and sedentary time appears partially mediated by central adiposity. That the association between birth weight and sedentary time became non-significant when controlling for waist circumference may be explained by multicollinearity between sedentary time and waist circumference. In addition, with a larger sample may the association have reached statistical significance. However, disregarding the statistical significance, the magnitude of the association was small, and a 1 kg increase in birth weight was only associated with 2.7 more minutes spent sedentary per day. This observation is opposite to some previous observations in animal models (106, 107), however consistent with the results of a previous study among those born with low to normal birth weights which were also unable to demonstrate an association between birth weight and sedentary time (150). Although sedentary time is different than not performing enough physical activity (151), studies using objectively measured physical activity have also been unable to demonstrate an association between birth weight and physical activity in youth (129, 150, 152). It has been suggested that across the normal birth weight spectrum, physical activity and sedentary time in youth are more influenced by environmental and behavioural factors than birth weight (129). On the other hand, the magnitude of the association between birth weight and sedentary time (and physical activity) could be underestimated due to the inherent variability of youth`s sedentary time and physical activity. A few days of measurement may not be representative of the true levels of sedentary time in our participants (153). It is also unknown whether the magnitude of association between birth weight and sedentary time changes by age and may become apparent in adulthood.

A limitation regarding the mediating role of abdominal adiposity in the present study is that the temporal sequence between waist circumference and sedentary time is not possible to establish. However, it has previously been shown that larger waist circumference predicts higher amounts of sedentary time in youth (91, 154), while sedentary time does not predict adiposity (91, 154, 155). In addition, reanalysing the data modelling sedentary time as the mediator and waist circumference as the outcome showed that, though significant, sedentary time attenuated the effect of birth weight on waist circumference with only 2% (compared with 32% when waist circumference was the mediator), supporting the use of waist circumference as a mediator in our analyses. Nevertheless, our results do not dismiss the possibility of a reverse causation, i.e. a bidirectional association between sedentary time and abdominal adiposity.

Earlier studies have shown that lower birth weight is associated with central adipose tissue in childhood (108, 156). In the present study, a higher birth weight was associated with higher waist circumference, however this association was attenuated by current BMI (results not shown). Interpreting associations between birth weight and obesity later in life which are substantially attenuated after adjustment for current body size (e.g. BMI) suggest that postnatal growth and change in size (e.g. weight centile crossing) between the time points may be more important factors on the causal pathway leading to abdominal adiposity than birth weight per se (157). As a result, public health strategies intended to influence the biology of fetal growth are most likely not the most essential approach, maybe with exception for obese pregnant women and those who have gestational diabetes, since both obesity during pregnancy and gestational diabetes are associated with large-for-gestational-age infants (158, 159). Rather strategies that aim to affect other factors such as postnatal weight gain are likely more successful to moderate the risk of obesity and metabolic diseases later in life, since rapid infant weight is associated with childhood obesity (160).

Methodological issues

There are several strengths of this study, including objectively measured sedentary time, a wide range of birth weights and a large and diverse sample representing different geographical and cultural locations. Even though the accelerometer data were reanalysed in a standardised manner and all analyses were adjusted for wear time, it is possible that differences in accelerometer wear protocol influenced the results. One of the included studies used a 24-hour monitor wear protocol and even if this difference was accounted for by excluding time between 24:00 and 07:00, this may have influenced the amount of time defined as sedentary time in this specific study. However, when reanalysing the data excluding this study, the findings were largely unchanged (data not shown).

The accelerometer is regarded as a valid tool for measuring physical activity and sedentary time (70, 121), however a hip placed monitor can be less effective in distinguishing sedentary postures, such as lying and sitting, from other light intensity activities performed while standing, and do not accurately capture upper body movement, cycling, walking in stairs, or other activities where the monitor is removed (e.g. water-based activities) (146, 161). Finally, non-wear time was subtracted from the wear time, and consequently prolonged quiet sitting could potentially have been considered as non-wear time, leading to an underestimation of sedentary time. The amount of time spent sedentary may differ between week- and weekend days. However, more than 85% of the participants in our dataset had at least one day of valid accelerometer data during a weekend day, and therefore I believe it is unlikely that this has affected our analyses of the association between birth weight and sedentary time. With the exception of one study, birth weight was reported retrospectively. However, it has been suggested that maternally recalled birth weight is highly correlated with measured birth weight and is sufficiently accurate to use in epidemiological studies (162). Waist circumference was used as the outcome for abdominal adiposity. Despite that abdominal adiposity is being recognised as an important determinant for disease and mortality (163), a more detailed measure of body composition may be preferred. Finally, I cannot exclude other unmeasured confounding variables including genotype, infant rapid weight gain, socioeconomic status and mothers BMI explained our findings. Future prospective studies with several measures of the mentioned confounder variables are needed to examine the potential mediating or modifying effects on the relationship between birth weight and later sedentary time at different ages.

Systematic review of prenatal, birth and early life predictors of sedentary behaviour (Paper IV)

The database searches resulted in more than 34,000 potentially relevant articles and details of the search and screening process are shown in Figure 5. In total, 16 unique studies including ten potential predictors were included.

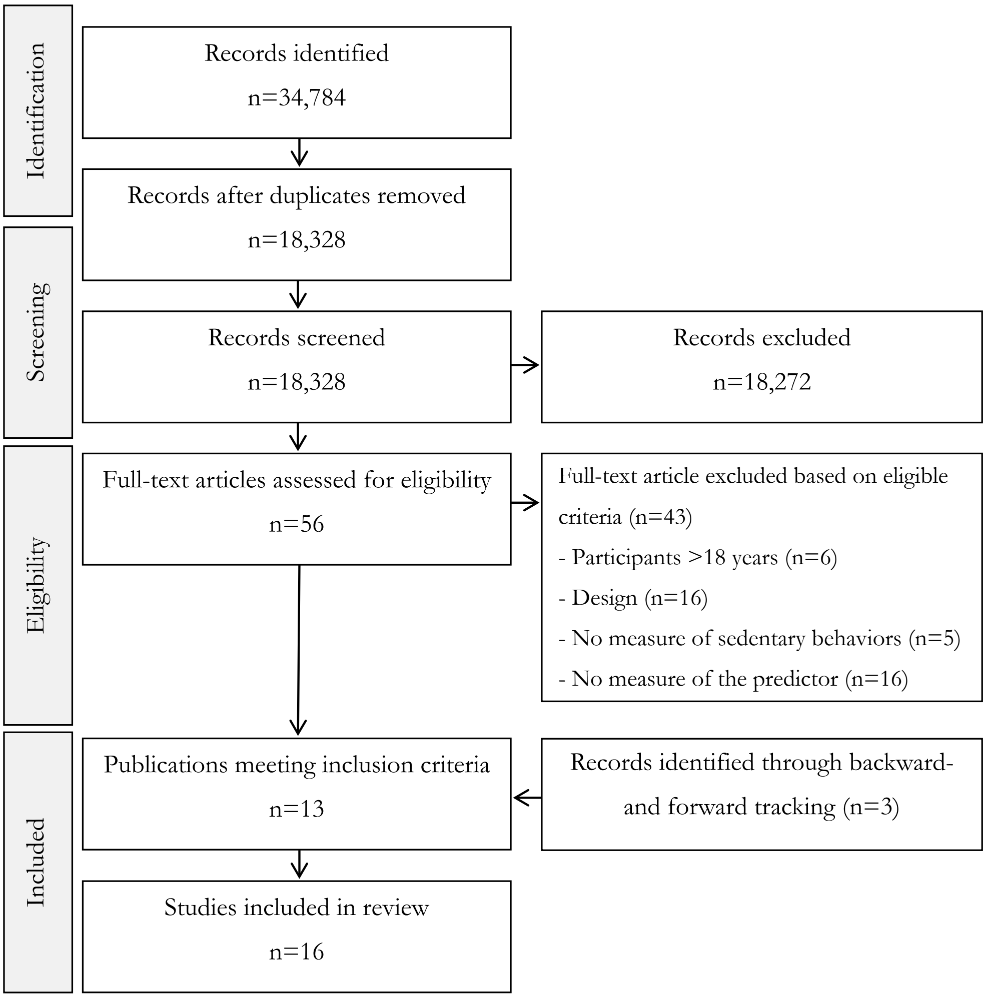

Figure 5. *Flow diagram of review process.*

Study characteristics

Descriptive of the included studies are shown in Table 7. Of the 16 included studies, eight were longitudinal prospective birth cohorts (164-171), while three studies had retrospective data collection (172-174), and two studies included a combination of both prospective and retrospective measures (150, 175). Three studies examining heritability of sedentary behaviour were cross-sectional twin studies (176, 177) or twin-family studies (i.e. including both twins and a non-twin siblings) (178). The majority of the studies were conducted in the USA (n=5) (166, 169, 172, 173, 176), UK (n=5) (150, 167, 171, 175, 177), or Australia (n=3) (164, 165, 168). All studies were published from 2010 and onwards, and the sample sizes ranged from 20 (172) to 10,793 participants (175). Eight studies measured sedentary time objectively (150, 167, 170-173, 175, 177), while the remaining studies used subjective methods, including self-reported screen time (168, 178), parent-reported TV-time (164-166, 169, 174), or a summary of time spent watching TV, sitting doing nothing and sitting listening to music (176). The included age groups at follow-up were 0-6 years (n= 4) (166, 169, 170, 173), 7-12 years (n=5) (164, 167, 172, 174, 177), or a combination of different age groups ≤18 years (n=7) (150, 165, 168, 171, 175, 176, 178).

Quality assessment

The included articles had a quality score between 0.36 and 0.95 (range 0 to 1), and 11 studies had a score above 0.80. The most common limitation was the use of a subjective and poorly validated measure of the outcome (n=8), such as parentally reported TV-viewing. Other limitations include incomplete description of participant selection (n=8), incomplete participant characteristics (n=6), variance estimates not provided for all results (n=7), lack of controlling for several confounding variables (n=5) and insufficient reporting of results (n=4).

Table 7. *Individual study characteristics of the included studies*

First author (year)	Country	Age, baseline (years)	Mean age (SD), follow-up (years)	n (% girls)	Assessment of sedentary behaviour	Predictor assessed	Quality assessment
Fisher (2010)	UK		11.2 (0.5)	234 (54)	Accelerometer	Heritability	0.91
Haberstick (2014)	USA		15.1 (2.2)	2,847 (52)	Self-report[4]	Heritability	0.77
van der Aa (2012)	NED		15.9 (1.6)	6,011 (56)	Self-report SCT	Heritability	0.86
Pearce (2012)	UK	0	8-10 (range)	482 (52)	Accelerometer	Maternal age, birth weight, gestational age, birth order	0.73
Wijtzes (2013)	NED	0-1	2.1 (0.1)	347 (48)	Accelerometer	Maternal age and pre-pregnancy weight, birth weight, gestational age, motor development, temperament	0.82
Pivarnik (2014)	USA		8-10 (range)	20	Accelerometer	Maternal PA	0.36
Byun (2011)	USA		4.3 (0.6)	331 (49)	Accelerometer	Birth weight	0.95
Gopinath (2013)	AUS		12.7 (0.4) 17-18 (range)	1,794 (50) 752 (53)	Self-report SCT	Birth weight	0.82
Hildebrand (2015)	ICAD[1]		6-18 (range)	10,793 (53)	Accelerometer	Birth weight	0.95
Peneau (2011)	FRA		7-9 (range)	2,207 (49)	Parent-report TV	Birth weight, gestational age	0.82
Ridgway (2011)	Overall[2]			4170		Birth weight	0.95
	EYHS[3]		12.0 (2.9)	1,240 (53)	Accelerometer		

	UK		14.5 (0.5)	811 (56)	Accelerometer		
	UK		10.2 (0.3)	1,647 (56)	Accelerometer		
	BRA	0	13.3 (0.3)	472 (48)	Accelerometer		
Lowe (2015)	UK	0	11	5327 (52)	Accelerometer	Gestational age	0.86
			15	1947 (55)			
Thompson (2013)	USA	3m-1	1.5	110-217	Parent-report TV	Temperament	0.86
Radesky (2014)	USA	9m	2.0	7450 (49)	Parent-report TV	Temperament	0.91
Fuller-Tyszkiewicz (2012)	AUS	2.3	4.3 (0.4)	4,724 (49)	Parent-report TV	BMI	0.64
			6.3 (0.5)				
		6.3	8.3 (0.4)	4,340 (49)			
			10.3 (0.5)				
Hands (2011)	AUS	6	8.1 (0.4)	1,271 (49)	Parent-report TV	BMI	0.77

AUS, Australia; BRA, Brazil; FRA, France; m, months; NED, Netherlands; PA, physical activity; SCT, screen time.

[1]*Data from eight studies in the International Children's Accelerometry Database (ICAD) collected in United Kingdom, Denmark, Estonia, Norway, Portugal, Switzerland and Brazil;* [2]*Data presented as overall from the meta-analysis and for each study included in the meta-analysis;* [3]*Data from the European Youth Heart Study (EYHS) collected in Norway, Portugal, Estonia and Denmark;* [4]*Include hours watching TV, sitting doing nothing and sitting listening to music per week.*

Prenatal predictors and sedentary behaviour

Maternal factors

No studies were identified that examined whether maternal smoking or maternal sedentary behaviour during pregnancy act as predictors of sedentary behaviour in the offspring. Based on a limited number of studies, there was no evidence for an association between maternal pre-pregnancy weight (170), maternal physical activity during pregnancy (172) and maternal age at birth (167, 170) and sedentary time in children aged 2 and 8-10 years. However, it is difficult to distinguish between the potential biological effects that may occur during fetal life due to for example maternal age (e.g. young mothers who are still growing might be competing for nutrients with the fetus, or higher maternal age could influence genetic abnormality (179)), and other non-biological differences later in life (e.g. behaviour, education, socioeconomic status). Due to the low number of studies, of which one was categorised as low quality, it is not possible to draw any firm conclusions of whether maternal factors during pregnancy may influence later sedentary behaviour in the offspring.

Heritability

In total three studies examined whether heritability influences sedentary behaviour in youth. Two studies found that heritability was a significant contributor on self-reported leisure sedentary time/screen time in children aged 12 years or older (176, 178), however one study reported higher heritability among girls (176), and the other among boys (178). This difference may be explained by different definitions of sedentary behaviour. While one study included time spent on computer and video games (178), which may be more common activities in adolescent boys than girls, this was not included in the other study (176). Finally, the last study observed a borderline non-significant heritability effect on the variance in objectively measured sedentary time in 9-12-year-old children (177), however a small sample size and a younger age group may explain the non-significant associations. It can be assumed that younger children are more influenced by non-heritable factors such as parents and the school environment than older children. This is supported by one of the studies showing an increased genetic contribution with increased age (178), and by studies in adults in which the heritability of sedentary behaviour appears greater in magnitude than in young people (>30%) (180-182). Additional studies are needed to identify regions within a genome contributing to variation in sedentary behaviour (182).

Birth weight

Seven studies examined the association between birth weight and sedentary behaviour. Based on six studies and adjusted analyses, there was no evidence for an associations between birth weight and objectively (150, 167, 170, 173) and subjectively (168, 174) measured sedentary behaviour. The seventh study used pooled data from eight studies (n=10,793) and found that high birth weight was associated with greater amount of time spent sedentary, however this association was partly mediated by waist circumference (175). Based on the results from the available literature, birth weight may not be an important predictor for sedentary behaviour in children and youth, and if such association is observed it may be explained by a positive association between higher birth weight and adiposity (175). These observations are in agreement with a recent meta-analysis in children and youth, on the association between birth weight and physical activity (183).

Birth predictors and sedentary behaviour

Ponderal index and birth order

I did not identify any study examining whether ponderal index at birth was associated with subsequent sedentary behaviour. One study found no evidence for an association between birth order and objectively measured sedentary time in 8 to 10-year-olds (167).

Gestational age

Previous studies suggest that being born preterm is associated with decreased lung function, which persists as a degree of functional impairment through life (184, 185). Therefore, children born preterm might be more sedentary compared to children born at term. I identified four studies all suggesting that gestational age (or preterm birth) was not associated with objectively (167, 170, 171) or subjectively (174) sedentary behaviour in young people, despite the fact that one study showed that preterm-born children had lung function deficits earlier in childhood (171). The results are further supported by studies showing no association between preterm birth and objectively measured physical activity in children (171) and adults (186). Children born preterm are often encouraged to be physically active, in order to promote their health, and this may therefore negate any tendency for preterm children to be less active than their term born peers.

Early life predictors and sedentary behaviour

Body weight and growth

Both infancy and childhood rapid weight gain are independent risk factors for later obesity (160, 187), and possibly predictors of sedentary behaviour since higher adiposity at one point appear to predict sedentary time later in childhood (188, 189). I did not identify any study examining whether infant and childhood growth patterns predict later sedentary behaviour, but two studies suggested that a higher BMI in 2-6-year-olds was associated with greater amount of time spent TV-viewing two or several years later (164, 165). However, dietary intake mediated the relationship for the older children in one of the studies (164). The reason why higher levels of adiposity may predict higher amounts of sedentary time is not known. Explanations such as musculoskeletal pain (114), negative body image (190), bullying (190), and physiological limitations including impaired mitochondrial function (191) and insulin resistance (192) have been suggested, but further research is needed to obtain a better understanding of the underlying mechanisms.

Temperament

Infant temperament has been associated with the risk for development of overweight and obesity in children (193) and it is plausible that the TV can be used to sooth and entertain children who are perceived as more aggressive and difficult to calm. Three studies examined early life temperament and sedentary behaviour, and the results were inconsistent. Among infants and toddlers, two studies found a positive association between crying duration (166) and having problems with self-regulation (i.e. sleep, mood and behaviour regulation and attention) (169) and viewing TV/video. In contrast, no association was found between two other dimensions of infant and toddlerhood temperament (i.e. activity level such as arm and leg movements, squirming etc. and fussiness) and objectively measured sedentary time/TV-exposure in children aged 1.5-2 years (166, 170). Explanation for the mixed results may be explained by the assessment of different dimensions of infant temperament, and diversity between studies. Two studies using parent-reported TV time suggest that the associations were stronger among mothers with low socioeconomic status (166, 169), and in overweight or obese mothers (166). Hence, it seems as strategies aimed at educating low income and often overweight mothers in other ways to cope with challenging temperament traits in their children rather than using the TV, may be an important intervention to reduce the development of not only sedentary behaviour, but also overweight and obesity among these children.

Motor development

Early motor development has been associated with higher physical activity in childhood (129, 183) and it is plausible that infants and children who experience later or impaired motor development automatically choose to be more sedentary. However, I did only identify one, relatively small study, suggesting no association between a delayed early life motor development and objectively measured sedentary time in 2-year-old children (170). In older children (10 years), higher motor coordination (i.e. ball throwing, one-foot balance and walking backwards) has been associated with less screen time in adolescence and adulthood (194). Therefore, studies with larger sample sizes and longer duration of follow-up are warranted to examine whether impaired motor development acts as a predictor of sedentary behaviour.

Methodological issues

Strengths of this review included a comprehensive search strategy, the use of a standardised protocol, an up to date search including papers published until December 2015 and the inclusion of several potential predictors for sedentary behaviour. As with any systematic review, the methodological quality is no better than the studies included in the review. The main limitations with the review are the small number of retrieved studies, heterogeneous data and methodological quality in the included studies. Despite the large number of high quality birth cohorts available globally, few have included measures of sedentary behaviour aimed at examining early life predictors of these behaviours. Eight out of 16 studies included in this review assessed sedentary time objectively by accelerometry. While a hip-placed accelerometer can provide sedentary data over a prolonged period, they are less valid in distinguishing sedentary postures, such as lying or sitting, from other light intensity activities performed while standing (195). In addition, different definitions of sedentary time and different data reductions methods may explain some of the dissimilarity in the results. Furthermore, the variability in time spent sedentary in children and adolescents is large, and only a few days of measurement may not be representative of the true levels of time spent sedentary (153, 196). Finally, specific environments (e.g. school) may reduce the between individual variability in sedentary time [96], and since young people spend most of their day at school, it is possible that accelerometer measurements during awake time will limit the possibility to detect associations with predicting factors. On the other hand, the ActivityStat hypothesis suggest that when physical activity is increased or decreased at one time, there will be a compensatory change at another time [97], so whether this issue has a large impact on the results is uncertain.

The majority of the studies assessing sedentary behaviour by self-report did not provide information about the validity and reliability of the measurement. Several of the identified studies included relatively small sample sizes and may not be adequately powered to identify weak, but true associations. The majority of the studies examined children aged 11 years or younger, and it is unknown whether the magnitude of the association between the examined predictors and sedentary behaviour changes by age and may become apparent later in life. Another limitation is the reliability of prenatal factors such as birth weight. Several studies used data from birth records or parentally reported at birth, which should provide accurate measurements, however some studies assessed birth weight retrospectively from the parents, which may be prone to misclassification. Finally, our aim was to examine physical factors that may be causally associated with the outcome, rather than those correlated with sedentary behaviour. The included studies examined prenatal, birth and infancy factors that precedes sedentary behaviour later in life, and several of the included studies were prospective in design, thereby allowing determination of the direction of associations. However, an observational study design does not provide proof of causation per se. Additional observational studies employing the Bradford Hill criteria (197) when evaluating the results or randomisation within a trial are warranted to determine causality.

Conclusions

1. Raw tri-axial accelerometer output from ActiGraph and GENEActiv seem comparable when attached to the same body location in adults, whereas inconsistent differences are apparent between the two brands and placements in children, maybe limiting the comparability between brands in this age group.
2. Laboratory derived sedentary thresholds generally overestimate sedentary time compared with activPAL during free-living activities. Wrist thresholds appear to perform better than hip thresholds for estimating free-living sedentary time in children and adults relative to activPAL, however, specificity for all the developed thresholds are low.
3. Birth weight is positively associated with sedentary time, however, the association appears partially mediated by central adiposity, suggesting that both birth weight and abdominal adiposity may predictors of sedentary time in youth.
4. The results from this systematic review suggest that heritability and early childhood BMI may predict sedentary behaviour in young people, while gestational age and birth weight might not be important predictors for sedentary behaviour. However, small number of studies included and methodological limitations, including subjective and poorly validated sedentary behaviour assessment, limits the conclusions.

Future perspectives

Future studies are needed to understand the underlying source of activity type specific differences between accelerometer output from the two monitors in children and the differences between age groups. Raw acceleration intensity thresholds from the two monitors when mounted on the wrist and the hip are presented, but further research using raw accelerometer output when developing intensity thresholds is needed before agreement can be reached on which thresholds should be used.

The evidence whether prenatal, birth and early life factors are predictors of sedentary behaviour is weak. There is a further need to understand whether associations develop through physical/mechanical pathways, for example accumulating adipose tissue might constrain physical movement; or through metabolic pathways, for example early adaptations in fuel metabolism might influence the availability for fuel utilisation for physical activity at later ages. This applies not only to the development within a child, but also the intergenerational associations of maternal pregnancy physiology with offspring sedentary behaviour. To increase our knowledge whether factors early in life influence not only health outcomes but also health-related behaviours such as sedentary behaviour and physical activity , including accurate and valid assessment of these behaviours or analysing existing data in high quality birth cohorts are warranted. The effect sizes for any association between prenatal, birth and early life predictors and sedentary behaviour appear small, and studies must be adequately powered enough to detect these modest, but perhaps important associations. Finally, although several potentially confounding factors have been included in existing studies, future studies may consider a wider range of both biological and socio-demographic confounders.

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Paper I

Age Group Comparability of Raw Accelerometer Output from Wrist- and Hip-Worn Monitors

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ABSTRACT

HILDEBRAND, M., V. T. VAN HEES, B. H. HANSEN, and U. EKELUND. Age Group Comparability of Raw Accelerometer Output from Wrist- and Hip-Worn Monitors. *Med. Sci. Sports Exerc.*, Vol. 46, No. 9, pp. 1816–1824, 2014. **Purpose**: The study aims were to compare raw triaxial accelerometer output from ActiGraph GT3X+ (AG) and GENEActiv (GA) placed on the hip and the wrist and to develop regression equations for estimating energy expenditure. **Methods**: Thirty children (7–11 yr) and 30 adults (18–65 yr) completed eight activities (ranging from lying to running) while wearing one AG and one GA on the hip and the wrist. Oxygen consumption ($\dot{V}O_2$) was measured with indirect calorimetry. Analysis involved the use of ANOVA to examine the effect of activity, brand, and placement on the acceleration values, intraclass correlation coefficient to evaluate the agreement between the two brands and placements, and linear regression to establish intensity thresholds. **Results**: A significant difference in acceleration values between the hip and the wrist placement was found ($P < 0.001$). The output from the wrist placement was, in general, higher compared with that from the hip. There was no main effect of monitor brand in adults ($P < 0.12$) and children ($P < 0.73$), and the intraclass correlation coefficient showed a strong agreement (0.96–0.99). However, a three-way interaction and systematic error between the brands was found in children. Acceleration from both brands and placements showed a strong correlation with $\dot{V}O_2$. The intensity classification accuracy of the developed thresholds for both brands and placements was, in general, higher for adults compared with that for children and was greater for sedentary/light (93%–97%), and vigorous activities (68%–92%) than that for moderate activities (33%–59%). **Conclusions**: Accelerometer outputs from AG and GA seem comparable when attached to the same body location in adults, whereas inconsistent differences are apparent between the two brands and placements in children, hence limiting the comparability between brands in this age group. **Key Words:** PHYSICAL ACTIVITY, OBJECTIVE MONITORING, ACTIVITY MONITORS, CHILDREN, ADULTS

Accurate measurement of physical activity (PA) and sedentary time is important for several reasons when examining these behaviors in observational and experimental studies in free-living individuals. This includes examining dose–response relations between PA, sedentary behavior, and various health outcomes, monitoring the effect of interventions in experimental studies, and determining levels and trends in PA and sedentary behavior in surveillance systems (41). Accelerometry is currently the most commonly used objective measurement of PA, and to date, several commercially available monitors have been validated to measure PA intensity or activity energy expenditure in both children and adults (1,19,24). The usual output from traditional accelerometers is in proprietary counts, making it difficult to compare data between different monitor brands. However, the latest versions of accelerometers, including ActiGraph GT3X+ (AG) and GENEActiv (GA), provide raw acceleration data expressed in gravity (*g*) units from three orthogonal axes. The raw data allow increased control over data processing (5) and, in theory, enable comparisons between acceleration data regardless of monitor brands. Nevertheless, the use of different accelerometer brands and different placements requires comparability studies for accurate interpretation of data across studies. Two previous studies have examined raw acceleration values from different monitors and placements with ground reaction force in adults (29,33). However, there is a paucity of data examining the comparability of the raw accelerometer output from different accelerometer brands using energy expenditure as the criterion method during structured activities of both children and adults.

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A second challenge in addition to the challenge of comparability between monitor brands is the comparability of raw accelerometer outputs from monitors placed on different body locations. Several large-scale epidemiological studies have assessed free-living PA among both children and adults using the AG and the GA, including the National Health and Nutrition Examination Survey (NHANES) (United States) (35) and UngKan2 (Norway) (34). However, in the ongoing data collection in the NHANES (2011–2014), a wrist placement of the AG is used compared with the hip placement used in previous NHANES sweeps (28). Limitations of a hip-placed accelerometer usually include underestimation of energy expenditure during activities with little or no movement at the hip in addition to the potential loss of data due to removal of the monitor when dressing, participating in some sports, for example, swimming, and while sleeping. Therefore, several studies have documented noncompliance resulting in loss of data when using a hip-mounted accelerometer (4,35). The advantage of the wrist placement is that it seems to facilitate long-term compliance (21,38). Also, the wrist placement allows for the examination of low-intensity PA such as arm movements during household work or when playing games and is commonly being used in studies examining sleep behaviors (7,14). Previous studies have suggested that a wrist-worn raw accelerometer accurately assesses overall PA among both children and adults (8,23); however, a wrist-mounted raw accelerometer may present challenges when trying to accurately identify different PA intensity thresholds (28).

Therefore, the aims of the present study were to make a standardized comparison between the raw triaxial accelerometer outputs from two raw accelerometers (AG and GA) and to determine whether the placement (hip and wrist) influences the accelerometer output during eight different activities of children and adults. In addition, we developed regression equations for estimating energy expenditure from raw accelerometer output using indirect calorimetry as the reference method.

METHODS

Participants. A convenient sample of 30 adults (17 women and 13 men) and 30 children (14 girls and 16 boys) was recruited from the staff and students from the Norwegian School of Sport Sciences (NSSS) and through schools and social media. The mean (± SD) ages of the adults and children were 34.2 ± 10.7 and 8.9 ± 0.9 yr, respectively. All participants were generally healthy, with no contraindications to PA or disorders affecting their energy expenditure or ability to perform the structured activities. The study falls outside the Remit of the Regional Committees for Medical and Health Research Ethics and therefore did not require approval from the institution. Instead, the study was approved by the Norwegian Social Science Data Services, which is NSSS' Data Protection Official for Research. The aim of the study was carefully explained to all participants, and a written informed consent was obtained from all participants or from the caregivers among those younger than 16 yr before participation.

Measurements. Participants were asked to visit the NSSS at one occasion to perform a laboratory-based protocol. Before attending the testing session, participants were asked to refrain from exercise the same day of testing and fast for at least 2 h. Weight was measured in light clothing to the nearest 0.1 kg using an electronic scale (Seca, Hamburg, Germany). Height was measured without shoes to the nearest 0.1 cm using a stadiometer (Seca, Hamburg, Germany).

The protocol consisted of eight structured activities. A complete description of the protocol is provided in Table 1. Activities were chosen to represent a variety of common daily activities for adults and children. Each activity was performed for 5 min, except for lying down, which lasted for 10 min, and the activities were separated by a 1-min break. Throughout all activities, the participants wore four activity monitors: one AG and GA on the right hip (midaxillary line) and one AG and GA on the nondominant wrist (dorsally midway between the radial and ulnar styloid processes). The monitors were attached next to each other with an elastic band on the wrist and hip, and both monitors were attached equally tightly to the location. The order of the monitors on the hip and wrist was counterbalanced to avoid any potential order effect.

The AG (ActiGraph, Pensacola, FL) and the GA (ActivInsights Ltd., Kimbolton, Cambridgeshire, United Kingdom) are small, lightweight triaxial accelerometers. The AG (4.6 × 3.3 × 1.5 cm, 19 g) measures acceleration between $-6g$ and $6g$, whereas the GA (4.3 × 4.0 × 1.3 cm, 16 g) measures acceleration between $-8g$ and $8g$. Acceleration values from both monitors are digitized by a 12-bit analog-to-digital converter at a user-specified rate ranging from 30 to 100 Hz. During this study, both monitors were set to collect raw triaxial acceleration at 60 Hz, and in total, 10 GA and 10 AG were used throughout the study. The interunit reliability has been found acceptable for both brands (8,30).

Oxygen consumption ($\dot{V}O_2$) was measured with an ergospirometry system with a mixing chamber, including O_2 (Electro Chemical Cell) and CO_2 analyzer (nondispersive infrared, thermopile) and pressure and temperature sensor (VMax Encore; SensorMedics, Bilthoven, Netherlands). Subjects breathed through a two-way mouthpiece (2700 Series,

TABLE 1. Description of the eight structured activities.

Activity	Description of Activity
Lying down	Lying in supine position awake, with arms at the side. Avoid bodily movement. Children were allowed to watch television.
Sitting	Sitting in a chair by a desk and using the computer
Standing	Standing on the floor. Adults were allowed to play with mobile phone, whereas children drew on whiteboard.
Circuit	Take off shoes standing, move eight things in a bookshelf, write a sentence, put a paper in an envelope, and sit down. Repeat.
Slow walking, 3 $km \cdot h^{-1}$	Walking on a treadmill
Fast walking, 5 $km \cdot h^{-1}$	Walking on a treadmill
Step	Walk up a step 15 times, and sit down. Repeat.
Running, 8 $km \cdot h^{-1}$	Running on a treadmill

2-way NRBY; Hans Rudolph, Inc., Shawnee, KS) and wore a mask covering the nose and mouth (7450 SeriesV2 Mask ORO-NASAL; Hans Rudolph, Inc., Shawnee, KS). The mask was fitted closely to minimize leakage. Standardized gas and flow calibration was performed before each testing. Flow was calibrated against a 3.0-L syringe (calibration syringe, series 5530; Hans Rudolph, Inc., Shawnee, KS), whereas CO_2 and O_2 were calibrated against gases of known concentration (95% N and 5% CO_2) (Aga Gas A/S; Leirdal, Oslo, Norway). $\dot{V}O_2$ was expressed in milliliters per kilogram per minute (mL $O^2 \cdot kg^{-1} \cdot min^{-1}$).

All devices were synchronized before testing. For all analyses, the triaxial acceleration values from AG and GA and $\dot{V}O_2$ during minutes 7.0–9.5 for lying and during minutes 2.5–4.5 for the other activities were calculated, allowing for a 2.5-min period to reach steady state for each activity.

Data reduction. Immediately after testing, the activity monitors were removed and the data were downloaded to a personal computer using the software supplied by the manufacturer (ActiLife software version 6.5.2 and GENEActiv personal computer software version 2.2). Raw triaxial acceleration values were converted into one omnidirectional measure of body acceleration. For this, the vector magnitude (VM) was taken from the three axes and then subtracted by the value of gravity (g) as in $(x^2 + y^2 + z^2)^{½} - 1$, after which, negative values were rounded up to zero, referred to as Euclidian norm minus one (ENMO) in a previous study (37). Data were further reduced by calculating the average values per 1-s epoch. We then calculated the average of these 1-s epoch values over the minutes included in the statistical analyses. Signal processing was done offline in R (http://cran.r-project.org/). The resulting values are expressed in gravity-based acceleration units (g), where g = 9.81 $m \cdot s^{-2}$. The R-code as applied to the laboratory data can be found in the supplement to this paper (see text R-code, Supplemental Digital Content 1, http://links.lww.com/MSS/A367, R-code to get ENMO). If the reader is interested in replicating these analyses for free-living accelerometer data, we recommend using R-package GGIR (26,37). This R-package facilitates data cleaning, like nonwear detection, and the extraction of user-defined acceleration levels, which can be set to reflect the intensity levels (MET values), as derived in this study. The calculation of metric ENMO in this R-package is identical to the calculation of ENMO used in the present study.

Data could not be extracted from three of the GA monitors (the hip and the wrist monitor of one adult in addition to one hip monitor worn by a child). Therefore, only 29 adults provided GA hip and wrist data, whereas 29 children provided GA hip data. In addition, six children were not able to perform the running activity on the specific velocity (8 $km \cdot h^{-1}$) and therefore ran at a lower velocity. These children are excluded from the ANOVA analysis but included in the regression analysis.

Data analysis. All data are expressed as mean values and SD, unless otherwise stated. Mixed between- and within-subjects ANOVA showed an age group (adults vs children) by output (acceleration) interaction; therefore, data from the two age groups were analyzed separately.

The effect of the activity, brand (AG and GA), and placement (hip and wrist) and the interaction effect (activity × brand × placement) on the output was tested by a factorial repeated-measures ANOVA. If assumptions of sphericity were violated ($P < 0.05$), the conservative Greenhouse–Geisser-corrected values of the degrees of freedom were used. Agreement between the two brands (AG and GA) and placement (hip and wrist) was evaluated by calculating intraclass correlation coefficient (ICC) using a two-way mixed-model ANOVA (type consistency). In addition, Bland–Altman analysis was used to assess the mean bias and the limits of agreement between monitors.

Linear regression analyses were performed to establish the relation between output and $\dot{V}O_2$ from the two monitor brands (AG and GA) and the two placements (hip and wrist). Intensity thresholds, expressed in gravity units (g), for moderate (3 METs) and vigorous (6 METs) intensities were calculated from the developed regression equations. We used the conversion 1 MET = mean measured resting energy expenditure during lying in children (6.0 mL $O_2 \cdot kg^{-1} \cdot min^{-1}$) and adults (3.5 mL $O_2 \cdot kg^{-1} \cdot min^{-1}$), respectively. Performance of the models was assessed using a 10–cross-validation mode (leave-one-out cross-validation). In addition, we applied the derived intensity thresholds to the sample to evaluate the intensity classification accuracy for each activity.

All statistical analyses were performed using the Statistical Package for the Social Sciences version 18.0 (SPSS, Inc., Chicago, IL). The level of statistical significance was set at $P < 0.05$.

RESULTS

The mean (SD) height, weight, and body mass index of the adult women and men were 168.3 (4.3) and 182.0 (5.4) cm, 69.6 (15.6) and 78.1 (7.0) kg, and 24.4 (4.6) and 23.6 (2.0) $kg \cdot m^{-2}$, respectively. The height, weight, and body mass index of the girls and the boys were 136.9 (8.3) and 137.0 (9.6) cm, 31.1 (6.4) and 31.2 (6.3) kg, and 16.7 (2.1) and 16.4 (1.4) $kg \cdot m^{-2}$, respectively. Table 2 shows the results for accelerometer output (mg) and $\dot{V}O_2$ (mL $O_2 \cdot kg^{-1} \cdot min^{-1}$) by activity. In general, increases in $\dot{V}O_2$ correspond to an increase in accelerometer output from both AG and GA at both placements. However, there are two exceptions to this. First, during the step activity, the outputs from both monitors at both placements were relatively lower compared with energy expenditure data ($\dot{V}O_2$). Second, GA placed at the hip produced a lower output in adults while sitting (not significant) and in children while sitting (P = 0.038) and standing (not significant) compared with that while lying, despite a lower oxygen uptake during lying.

In both children and adults, a factorial ANOVA showed a significant effect of activity ($F_{2.1,47.9}$ = 355.2, $F_{1.3,35.5}$ = 1031.7, $P < 0.0001$) and placement ($F_{1.0,23.0}$ = 31.7, $F_{1.0,27.0}$ = 83.3, $P < 0.0001$), with significantly higher output from the wrist

TABLE 2. Mean (SD) accelerometer output from AG and GA (m*g*) and $\dot{V}O_2$ (mL $O^2 \cdot kg^{-1} \cdot min^{-1}$) during each activity performed by adults and children.

		Lying Quietly	Sitting	Standing	Circuit	Slow Walk, 3 $km \cdot h^{-1}$	Fast Walk, 5 $km \cdot h^{-1}$	Step	Running, 8 $km \cdot h^{-1}$
Adults (*n* = 30)	AG hip	2.22 (6.25)	4.41 (8.47)	9.75 (13.17)	24.93 (22.62)	69.80 (20.67)	156.65 (23.35)	70.12 (34.74)	465.89 (75.21)
	GA hip[a]	2.86 (6.20)	1.90 (3.48)	14.23 (55.48)	19.15 (25.06)	69.10 (26.29)	156.25 (26.52)	69.87 (39.29)	475.96 (76.92)
	AG wrist	7.16 (10.89)	11.78 (23.45)	22.11 (28.46)	71.84 (64.78)	81.88 (35.91)	177.22 (63.52)	91.94 (49.33)	765.03 (202.77)
	GA wrist[a]	0.31 (1.34)	4.31 (11.94)	9.08 (15.71)	65.34 (63.75)	72.90 (28.87)	169.80 (56.25)	85.67 (46.31)	761.30 (200.29)
	$\dot{V}O_2$	3.5 (0.5)	3.7 (0.8)	3.9 (0.9)	8.9 (2.3)	8.7 (1.3)	11.8 (1.2)	13.0 (2.2)	26.1 (2.9)
Children (*n* = 30)	AG hip	5.56 (12.38)	10.51 (13.85)	18.41 (17.52)	29.50 (26.09)	91.66 (28.26)	194.55 (41.75)	149.60 (196.89)	534.71 (84.69)[b]
	GA hip[a]	14.28 (18.49)	7.65 (19.18)	14.02 (29.63)	26.48 (36.21)	91.80 (32.31)	199.75 (47.24)	158.28 (223.25)	589.89 (114.46)[b]
	AG wrist	8.37 (22.75)	14.66 (26.72)	33.03 (42.15)	74.73 (77.25)	100.60 (53.72)	219.00 (99.42)	168.90 (202.73)	817.15 (235.40)[b]
	GA wrist	2.32 (10.56)	3.83 (12.08)	21.37 (37.09)	65.33 (80.27)	89.38 (47.30)	206.64 (88.24)	156.84 (210.56)	809.10 (231.14)[b]
	$\dot{V}O_2$	6.0 (1.0)	6.4 (1.2)	6.7 (1.7)	10.6 (2.4)	12.8 (1.9)	17.0 (2.1)	19.8 (6.9)	33.0 (3.0)[b]

[a] *n* = 29.
[b] *n* = 24.

monitors than that from the hip monitors ($P < 0.001$). A significant interaction effect of activity and placement on the acceleration output was observed in both groups ($F_{1.5,35.2}$ = 36.6, $F_{1.2,32.7}$ = 79.7, $P < 0.0001$). Compared with the output from the monitor on the hip, the output from the wrist monitor was higher during the more intense activities but similar or lower during the sedentary activities, including lying and sitting (see figure, Supplemental Digital Content 2, http://links.lww.com/MSS/A368, showing the acceleration values from the monitors for each activity). No significant main effect of brand was observed in children and adults ($P = 0.73$ and $P = 0.12$, respectively).

A significant three-way interaction effect (activity × placement × brand) was observed in children ($F_{2.0,46.5}$ = 8.2, P = 0.001). *Post hoc* analysis per activity showed a significant interaction between placement and brand during four activities, including lying ($F_{1.0,28.0}$ = 8.1, P = 0.008), step ($F_{1.0,28.0}$ = 18.9, $P < 0.0001$), slow walking ($F_{1.0,28.0}$ = 7.2, P = 0.012), and running ($F_{1.0,23.0}$ = 16.6, $P < 0.0001$). During these four activities, GA produced a higher output than that in AG when placed on the hip (only significant during running, 10.5% difference, $P < 0.0001$) whereas GA produced a lower output than that in AG when placed on the wrist (significant during the step activity and slow walking, 9.6% and 9.1% difference, $P < 0.0001$). In adults, no significant three-way interaction (activity × placement × brand) was observed ($P = 0.49$).

Figure 1 displays Bland–Altman plots showing the mean bias and 95% limits of agreement between AG and GA

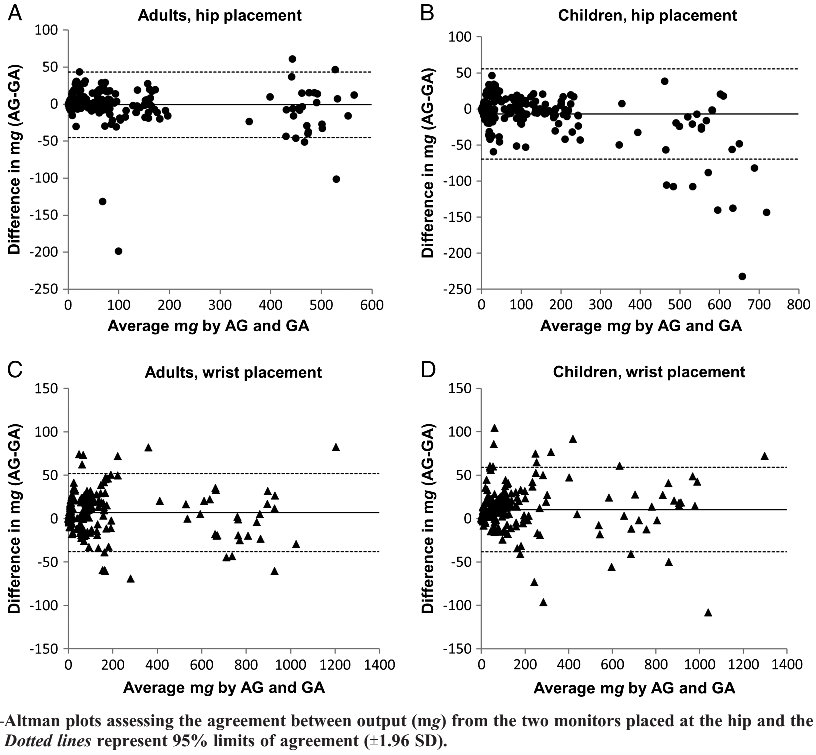

FIGURE 1—Bland–Altman plots assessing the agreement between output (m*g*) from the two monitors placed at the hip and the wrist for adults and children separately. *Dotted lines* represent 95% limits of agreement (±1.96 SD).

TABLE 3. Regression equations developed for the prediction of intensity (METs) from AG and GA placed on the hip and wrist, respectively, in adults and children.

		Equation	95% CI for α	95% CI for β	R^2
Adults (*n* = 30)	AG hip	$\dot{V}O_2 = 0.0554\ mg + 6.67$	0.0551–0.0557	6.61–6.72	0.81
	GA hip[a]	$\dot{V}O_2 = 0.0530\ mg + 6.86$	0.0527–0.0533	6.81–6.92	0.79
	AG wrist	$\dot{V}O_2 = 0.0320\ mg + 7.28$	0.0318–0.0322	7.22–7.34	0.75
	GA wrist[a]	$\dot{V}O_2 = 0.0323\ mg + 7.49$	0.0321–0.0325	7.43–7.54	0.76
Children (*n* = 30)	AG hip	$\dot{V}O_2 = 0.0559\ mg + 10.03$	0.0556–0.0563	9.96–10.10	0.78
	GA hip[a]	$\dot{V}O_2 = 0.0498\ mg + 10.39$	0.0495–0.0501	10.31–10.47	0.75
	AG wrist	$\dot{V}O_2 = 0.0356\ mg + 10.83$	0.0353–0.0358	10.75–10.91	0.71
	GA wrist	$\dot{V}O_2 = 0.0357\ mg + 11.16$	0.0355–0.0360	11.08–11.24	0.72

$\dot{V}O_2$ is expressed in milliliters per kilogram per minute (mL $O^2 \cdot kg^{-1} \cdot min^{-1}$).
[a] *n* = 29.

placed at the hip in adults (Fig. 1a) and children (Fig. 1b) and for the wrist placement in adults (Fig. 1c) and in children (Fig. 1d). Mean bias and 95% limits of agreement (m*g*) for the two placements and age groups were as follows: 1a) −0.8 (−3.7 to 2.1), 1b) −6.9 (−11.1 to −2.8), 1c) 6.7 (3.7–9.7), and 1d) 10.3 (7.1–13.5). A significant negative correlation was observed between average acceleration values and difference in values from the hip-placed monitors in both adults (−0.16, $P = 0.013$) and children (−0.55, $P < 0.0001$), which was most pronounced during higher acceleration values (Fig. 1).

ICC and 95% CI between different brands (AG and GA) placed at the hip for adults and children were 0.979 (0.979–0.980) and 0.964 (0.929–0.932), respectively, and 0.987 (0.986–0.987) and 0.976 (0.976–0.977), respectively, for the wrist placement. ICC and 95% CI between different placement (hip and wrist) for adults and children were 0.899 (0.896–0.901) and 0.903 (0.901–0.905), respectively, for AG and 0.905 (0.903–0.907) and 0.917 (0.916–0.919), respectively, for GA.

Linear regression analysis was performed to examine the associations between output from the AG and GA monitors and $\dot{V}O_2$. The developed prediction equations are shown in Table 3. Acceleration output from both AG and GA at the two different placements explained a significant proportion of the variance (R^2) in $\dot{V}O_2$. The R^2 for monitors placed at the wrist ranged between 71% and 78% in children and between 75% and 81% in adults, with consistently (4%–6% units) lower R^2 for wrist compared with that for hip placements.

Table 4 shows the intensity thresholds for moderate (3 METs) and vigorous (6 METs) intensity from the different monitors and placements in adults and children. Intensity thresholds were consistently higher in children than those in adults, although they were fairly similar between monitor brands at the same placement in the two age groups. Results from the 10 cross-validations (leave-one-out cross-validation) on both brands and locations showed that between 93% and 96% of the light/sedentary values, 54% and 59% of the moderate values, and 89% and 92% of the vigorous values were correctly classified in adults. In children, between 96% and 97% of the light/sedentary values, 33% and 55% of the moderate values, and 68% and 80% of the vigorous values were correctly classified. Table 5 shows the intensity accuracy for the developed intensity thresholds for all activities. The lowest intensity classification accuracy was observed during the step and circuit activities.

DISCUSSION

The availability of multiple brands of accelerometer and the deployment of different body placement locations across studies when assessing free-living PA call for a better understanding of the agreement between outputs from different accelerometer brands across placement positions when performing activities of daily life. The present study compared raw triaxial acceleration values from AG and GA placed at the hip and wrist in children and adults performing a variety of lifestyle activities and developed intensity thresholds for the accelerometer output corresponding to moderate-intensity PA (MPA) (3 METs) and vigorous-intensity PA (VPA) (6 METs).

A significantly higher output was observed from the wrist-mounted monitors compared with that from the hip-mounted monitors. For example, output from the wrist monitors was up to 200% higher than the output from the hip monitors during the step activity in some individuals. In relation to $\dot{V}O_2$, the results showed a slightly higher explained variance for the hip-mounted monitors compared with that for the wrist-mounted monitors in both children and adults. These results are in accordance with several previous studies that have compared a hip-placed monitor with a wrist-placed monitor (3,7,8,23,28,42). However, the wrist placement performed well and taking into account that this placement may be less obtrusive compared with a hip placement and therefore increases compliance in studies, the wrist placement seems a feasible option.

The overall results from the ANOVA analysis demonstrated no main difference between the two brands in adults or children, and the ICC showed a high agreement. However, a significant three-way interaction (activity × placement × brand) was observed among children, suggesting

TABLE 4. Derived acceleration intensity thresholds (m*g*) for MPA (3 METs) and VPA (6 METs) in children and adults, respectively.

		3 METs	6 METs
Adults (*n* = 30)	AG hip	69.1	258.7
	GA hip[a]	68.7	266.8
	AG wrist	100.6	428.8
	GA wrist[a]	93.2	418.3
Children (*n* = 30)	AG hip	142.6	464.6
	GA hip[a]	152.8	514.3
	AG wrist	201.4	707.0
	GA wrist	191.6	695.8

[a] *n* = 29.

TABLE 5. Intensity classification accuracy (%) for regression models from AG and GA during each activity performed by adults and children.

		Lying Quietly	Sitting	Standing	Circuit	Slow walk, 3 km·h^{-1}	Fast walk, 5 km·h^{-1}	Step	Running, 8 km·h^{-1}
Adults (n = 30)	AG hip	S/L: 100	S/L: 100	S/L: 100	S/L: 100	S/L: 18	S/L: —	S/L: —	S/L: —
		M: —	M: —	M: —	M: 0	M: 53	M: 100	M: 54	M: —
		V: —	V: —	V: —	V: —	V: —	V: —	V: 0	V: 100
	GA hip[a]	S/L: 100	S/L: 100	S/L: 93	S/L: 100	S/L: 18	S/L: —	S/L: —	S/L: —
		M: —	M: —	M: —	M: 0	M: 47	M: 100	M: 44	M: —
		V: —	V: —	V: —	V: —	V: —	V: —	V: 0	V: 100
	AG wrist	S/L: 100	S/L: 97	S/L: 100	S/L: 100	S/L: 55	S/L: —	S/L: —	S/L: —
		M: —	M: —	M: —	M: 10	M: 16	M: 100	M: 46	M: —
		V: —	V: —	V: —	V: —	V: —	V: —	V: 0	V: 97
	GA wrist[a]	S/L: 100	S/L: 100	S/L: 100	S/L: 100	S/L: 80	S/L: —	S/L: —	S/L: —
		M: —	M: —	M: —	M: 0	M: 5	M: 100	M: 30	M: —
		V: —	V: —	V: —	V: —	V: —	V: —	V: 0	V: 97
Children (n = 30)	AG hip	S/L: 100	S/L: 100	S/L: 100	S/L: 100	S/L: 100	S/L: 0	S/L: 100	S/L: —
		M: —	M: —	M: —	M: 0	M: 14	M: 96	M: 29	M: 100
		V: —	V: —	V: —	V: —	V: —	V: —	V: 33	V: 91
	GA hip[a]	S/L: 100	S/L: 100	S/L: 100	S/L: 100	S/L: 100	S/L: 0	S/L: 100	S/L: —
		M: —	M: —	M: —	M: 0	M: 0	M: 85	M: 21	M: 0
		V: —	V: —	V: —	V: —	V: —	V: —	V: 67	V: 82
	AG wrist	S/L: 100	S/L: 100	S/L: 100	S/L: 100	S/L: 96	S/L: 50	S/L: 100	S/L: —
		M: —	M: —	M: —	M: 0	M: 0	M: 50	M: 13	M: 100
		V: —	V: —	V: —	V: —	V: —	V: —	V: 0	V: 79
	GA wrist	S/L: 100	S/L: 100	S/L: 100	S/L: 100	S/L: 96	S/L: 0	S/L: 100	S/L: —
		M: —	M: —	M: —	M: 0	M: 0	M: 64	M: 13	M: 100
		V: —	V: —	V: —	V: —	V: —	V: —	V: 0	V: 79

The values between 0 and 100 indicate the accuracy expressed in percentages for the regression models compared with the true intensity measured with indirect calorimetry (i.e., 0 means that no individuals at this intensity were correctly classified by the regression model, whereas 100 means that all individuals were correctly classified at this intensity by the regression model). The dashes indicate that no individuals had this intensity measured by indirect calorimetry.

[a] n = 29.

M, moderate-intensity 3–6 METs; S/L, sedentary and light intensity <3 METs; V, vigorous intensity >6 METs.

that the accelerometer output between the two brands placed at the hip or the wrist is comparable for some but not all of the studied activities. For example, the output from GA placed on the hip was 11% higher compared with that from AG during running, whereas GA placed on the wrist was 9% lower compared with AG during step activity and slow walking. The difference in acceleration values between AG and GA placed on the hip also increased during higher accelerometer output, especially in children (Fig. 1). However, the largest difference observed between hip-mounted brands when running at 8 km·h^{-1} in children was 50 mg, which equates to a difference of 2–3 mL·kg^{-1}·min^{-1} in $\dot{V}O_2$, which may not be clinically relevant. We did not observe a clear pattern in the differences in acceleration values between the two brands and placements, and we can only speculate why the output from the monitors varies and why it is greater in children. There are several technical factors influencing the signal output by the microelectromechanical system, including bandwidth, filter strategy, sampling rate, dynamic range, sensitivity, signal noise, and data resolution. The microelectromechanical sensor differs between the two accelerometer brands. The GA uses the Analog Devices ADXL345, whereas AG uses the Kionix® KXSC7-3672 (Kionix, Ithaca, NY) accelerometer. The raw data are not filtered by the GA accelerometer, whereas AG applies filtering but decides to keep the details of this filtering process proprietary (13). In addition, an interaction between differences in sensor positioning and subtle differences between the devices may have influenced the results. Finally, consistent and accurate attachment of accelerometers in children is more challenging because of their smaller body size. Although the absolute distance between the two accelerometer brands might be the same, the relative difference (relative to rotating body) is greater, which may explain a greater difference in monitor output.

The magnitude of accelerometer output provides a reasonably valid measure of overall PA (37). However, most international PA recommendations for public health are based on the amount of time spent in MPA and VPA (2,12,17,40). Keeping in mind that the intensity thresholds for MPA and VPA defined in any calibration study are dependent on the calibration activities included, we derived such thresholds from the accelerometer output for both monitors at the two different placements. Interestingly, the derived intensity thresholds for MPA and VPA were remarkably similar between monitor brands placed at the hip (<3% difference) and the wrist (<8% difference), possibly with the exception for the hip placement in children (7%–11% difference). The cross-validation of the intensity thresholds suggests that sedentary/light and vigorous activities, for example, lying, sitting, and standing in addition to fast walking and running, were accurately classified most of the time from both monitors at both locations, whereas the moderate-intensity activities, for example, stepping and circuit, showed lower accuracy, especially in children (33%–55%). Because this is the first study to report intensity thresholds for AG and GA expressed in gravity units (g), it is not possible to directly compare our results with those from previous studies. However, two studies have derived PA intensity thresholds for a similar device (GENEA), in agreement with our observations; they reported higher-intensity threshold values for wrist placement compared with those for hip placement (8,23). When comparing our results with those of recently published studies (8,23), the following differences need to be considered. First, it is unclear if the accelerometer outputs from the different monitors (GENEA vs GA) are directly comparable. Second, the two previous studies used another approach for data reduction compared with that in ours. In the present study, negative values resulting from subtracting the VM by 1*g* were replaced by zero, whereas in the studies by Esliger et al. (8) and Phillips et al. (23), the negative values were replaced by their absolute value. Negative values are potentially a result of calibration error and not related to body movement, which is why rounding them to zero seems preferable. It is also acknowledged that downward accelerations may cause negative VM values. However, taking the absolute of a negative value will only correct for these negative accelerations in the lower acceleration range and therefore introduce nonlinearity into the overall range in VM values, suggesting that rounding negative acceleration values to zero may be preferable. Next, the resulting values in the previous studies were summed per second rather than averaged per second (8,23). Summing the resulting values may introduce an undesirable dependency on sample frequency, complicating comparison of results across studies based on different sample frequencies. The use of the average gravity-based acceleration (*g*) means that the intensity thresholds derived in this study could be used irrespective of sampling frequency or epoch length, hence facilitating easy comparisons across studies. However, it should be noted that a longer epoch is associated with an increased chance for capturing multiple activity types or multiple intensities within an epoch, which may then blur the average acceleration and make the data harder to interpret, which is a generic phenomenon that also applies to energy expenditure data measured by indirect calorimetry. Finally, our results are expressed in gravity units (*g*), whereas the other values were expressed in gravity-based acceleration (*g*) seconds. Taking all of those previously mentioned in consideration, we recommend the use of the present data reduction method in future studies to enable data comparison between studies.

The importance of accurate measurement of sedentary behavior, defined as seated or reclined postures characterized by an energy expenditure ≤1.5 METs, has gained interest in recent years (9,22). Accelerometers estimate time spent sedentary by the absence of movement (18). In the present study, a generally lower accelerometer output was observed while sitting and lying than that during standing and other activities. The derived intensity thresholds classified lying, sitting, and standing correctly as sedentary/light-intensity activities when compared with measured energy expenditure. However, according to the definition of sedentary behavior (22), this may suggest that average magnitude of acceleration is less effective in distinguishing sedentary postures, such as lying and sitting, from other light-intensity activities performed while standing. This corresponds with earlier studies that have shown that there are difficulties in measuring sedentary time with a single-mounted accelerometer (15,20,28). It has been stated that accurately identifying sedentary behavior from lack of wrist motion presents significant challenges (28) and AG placed at the hip has been found to not accurately estimate total sedentary time or the number of breaks in sedentary time (20).

There are several limitations in the present study that warrant consideration. The sample was a convenient sample consisting of healthy children and adults and did not include obese individuals. In addition, the sample consisted of two age groups, and therefore, the results cannot be applied to other age groups (e.g., elderly). The study only included indoor activities. The selection of activities in any calibration protocol will probably alter the association between acceleration output and oxygen uptake; hence, the derived intensity thresholds from this study may only be valid for the activities performed. However, sitting, standing, and locomotion at different speeds likely contribute to the vast majority of waking hours in most individuals. Finally, it has been suggested that the single-regression equation developed to calculate intensity thresholds is not able to accurately predict time spent in different intensities across a wide range of activities (16,19,36). Alternatively, other methods for analyzing output from accelerometers are likely to improve the estimation of intensity from acceleration (6,25,32).

The present study also has several strengths. First, similar to previous studies (7,10,23,27), we used a variety of common daily activities not only restricted to treadmill activity when establishing the relation between acceleration and $\dot{V}O_2$ to mimic free-living activities. Furthermore, both children and adults spend most of their time being sedentary (11,31,39) and a strength of the current study is that the protocol included sedentary activities like lying and sitting. Finally, we assessed oxygen uptake by indirect calorimetry, considered the gold standard for energy expenditure measurements, and measured resting energy expenditure individually in all participants.

In conclusion, significant and inconsistent differences are apparent when comparing the two brands and placements in children. In adults, accelerometer outputs from the two brands seem comparable when attached to the same body location. Future studies are needed to understand the underlying source of activity type-specific differences between accelerometer output from the two monitors in children and the differences between age groups. Raw acceleration intensity thresholds for moderate- and vigorous-intensity activities from the two monitors when mounted on the wrist and the hip are presented but need to be confirmed in future studies.

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Paper II

Paper III

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Association between birth weight and objectively measured sedentary time is mediated by central adiposity: data in 10,793 youth from the International Children's Accelerometry Database[1–3]

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ABSTRACT

Background: Birth weight is an early correlate of disease later in life, and animal studies suggest that low birth weight is associated with reduced activity and increased sedentary time. Whether birth weight predicts later sedentary time in humans is uncertain.

Objectives: We examined the relation between birth weight and sedentary time in youth and examined whether this association was mediated by central adiposity.

Design: We used pooled cross-sectional data from 8 observational studies conducted between 1997 and 2007 that consisted of 10,793 youth (boys: 47%) aged 6–18 y from the International Children's Accelerometry Database. Birth weight was measured in hospitals or maternally reported, sedentary time was assessed by using accelerometry ($<$100 counts/min), and abdominal adiposity (waist circumference) was measured according to WHO procedures. A mediation analysis with bootstrapping was used to analyze data.

Results: The mean ($\pm$SD) time spent sedentary was 370 ± 91 min/d. Birth weight was positively associated with sedentary time ($B = 4.04$, $P = 0.006$) and waist circumference ($B = 1.59$, $P < 0.001$), whereas waist circumference was positively associated with sedentary time ($B = 0.82$, $P < 0.001$). Results of the mediation analysis showed a significant indirect effect of birth weight on sedentary time through waist circumference (B: 1.30; 95% bias-corrected CI: 0.94, 1.72), and when waist circumference was controlled for, the effect of birth weight on sedentary time was attenuated by 32% ($B = 2.74$, $P = 0.06$).

Conclusion: The association between birth weight and sedentary time appears partially mediated by central adiposity, suggesting that both birth weight and abdominal adiposity may be correlates of sedentary time in youth. *Am J Clin Nutr* doi: 10.3945/ajcn.114.103648.

Keywords: abdominal adiposity, birth weight, sedentary time, youth, mediation, accelerometry

INTRODUCTION

The Developmental Origins of Health and Disease hypothesis suggests that nonoptimal growth and environmental conditions during fetal life may result in permanent changes in the body's structure, function, and metabolism (1). These irreversible adaptations can increase risk of diseases later in life, and birth weight, which is used as an indicator of intrauterine growth and the prenatal environment (2), is inversely associated with increased risk of all-cause mortality (3), cardiovascular disease (4), and type 2 diabetes later in life (5). In addition, a low birth weight is associated with reduced muscle mass and strength (6, 7) as well as lower aerobic fitness later in life (7–9). A lower probability of undertaking leisure-time physical activity later in life in individuals born with low or high birth weight was also suggested (10).

Animal studies showed that the offspring of undernourished mothers are less active and more sedentary than offspring born within normal birth weights (11, 12). In humans, the current knowledge on whether birth weight is associated with behaviors such as sedentary time is limited. One study that used an objective

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measure of sedentary time showed no associations with birth weight; however, analyses were limited to subjects born in the low-to-normal weight spectrum of birth weights (13). In addition, knowledge about the mechanisms that may underpin a potential association between birth weight and sedentary time is scant; in the current study, we hypothesized that central adiposity is one such mechanism.

A higher birth weight is associated with increased risk of obesity (14), greater overall fat mass (15), and higher BMI (16), whereas a lower birth weight is related to a higher percentage of body fat (17) and central adipose tissue in youth (16, 18, 19). Therefore, it was suggested that both overnutrition and undernutrition during fetal life can trigger pathways responsible for obesity later in life (19). In addition, obesity appears to be associated with and shares the same pathophysiologic mechanisms as low cardiorespiratory fitness and muscle mass (20), and although studies that used both objective (21–24) and subjective (25) measures suggested that higher amounts of sedentary time may not predict central adiposity, the reverse was reported in young people (21, 23, 24). Therefore, it is plausible that central adiposity may mediate a potential association between birth weight and sedentary time in youth.

Because of the high amount of time spent sedentary in youth (26, 27) and the potential independent harmful effects of excessive sedentary behavior on numerous health outcomes later in life (25, 28, 29), an understanding of potential correlates and determinants of this behavior is important to provide evidence for public health interventions aimed at reducing sedentary time. Thus, the aims of this study were to examine the relation between birth weight and objectively measured sedentary time and whether this association is mediated by central adiposity.

METHODS

Study design and participants

The International Children's Accelerometry Database (ICAD)[4] (http://www.mrc-epid.cam.ac.uk/Research/Studies/) was established to pool data on objectively measured physical activity and sedentary time from observational studies in youth worldwide. Aims, design, inclusion criteria, and methods of the ICAD project have been described in detail previously (30). Briefly, the ICAD consists of re-analyzed and pooled accelerometer data combined with phenotypic information in ~32,000 young people aged 3–18 y. Ethical approval was granted for each individual study, and all participants have provided informed parental consent. Formal data-sharing agreements were established, and all partners consulted with their individual research boards to confirm sufficient ethical approval had been attained for contributing data. For this study, data from 8 studies conducted between 1997 and 2007, in which measured or maternally reported birth weight, measured waist circumference, and sedentary time were available (n = 10,793) were included (31–40). This subsample (aged 6–18 y) differed slightly from the whole ICAD sample in terms of time spent sedentary (+16 min/d; 4.3%; $P < 0.001$) and waist circumference (+1 cm; 1.5%; $P < 0.001$).

Measurements

A detailed description of the assessment of sedentary time and physical activity is available elsewhere (30). Accelerometer data in the ICAD were re-analyzed centrally in a standardized manner with specialist software (KineSoft Software, version 3.3.20; Kinesoft.org) (30) and processed in 60-s epochs to provide comparable physical activity outcomes across studies.

The Pelotas study used a 24-h wear protocol, whereas the other studies asked participants to wear the accelerometer during waking hours only. To avoid accelerometer data being influenced by the increased wear time, accelerometry data were excluded for the overnight period between 2400 and 0700 in the Pelotas study. Children with ≥3 d with 600 min of measured monitor wear time between 0700 and midnight were included. Nonwear time was defined as 60 min of consecutive zeroes, with the allowance for 2 min of nonzero interruptions, terminated at the third nonzero interruption (41, 42). Overall physical activity was calculated as total counts over the wear period and expressed in counts per minute. The time spent sedentary was defined as all minutes with <100 counts/min (43), whereas the time spent in moderate-to-vigorous physical activity (MVPA) was defined as minutes with >3000 counts/min (44). Both sedentary time and time spent in MVPA are expressed in minutes per day.

Height and weight were measured by using a standardized procedure across studies. BMI (weight divided by height squared) was calculated for each participant, and age- and sex specific BMI cutoffs were used to categorize participants as normal weight, overweight, or obese (45). Waist circumference was used as a surrogate measure for abdominal adiposity and measured according to WHO procedures by using a metal anthropometric tape midway between the lower rib margin an iliac crest at the end of a gentle expiration (46). Birth weight was directly measured (Pelotas study) or maternally reported, which has been shown to be highly correlated with measured birth weight (47).

Statistical analyses

Means (±SDs) are shown for descriptive variables. An independent t test was used to compare descriptive data between sexes.

We used resampling strategies and the macro presented by Preacher and Hayes (48) to assess whether waist circumference (cm) acts as a potential mediator of the association between birth weight (kg) and sedentary time (min/d). Bootstrapping is a nonparametric resampling procedure that does not require the assumption of normality of the sampling distribution and is a recommended method of obtaining confidence limits for indirect effects. The method involves repeated sampling from the data set, and the indirect effect is estimated in each resampled data set (48). In the unstandardized regression equation (ordinary least-squares regression), birth weight was modeled as the predictor, sedentary time was modeled as the outcome, waist circumference was modeled as the mediator, and sex, age, study, and monitor wear time were modeled as covariates. Analyses were used to determine the total (c path) and direct effect (c' path) of birth weight on sedentary time and estimate the mediating role

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[4] Abbreviations used: bCI, bias-corrected CI; ICAD, International Children's Accelerometry Database; MVPA, moderate-to-vigorous physical activity.

of waist circumference (the $a \times b$ products; indirect effect of the independent variable on the dependent variable through the mediator). In the current study, a 95% bias-corrected CI (bCI) for each $a \times b$ product was obtained with 5000 bootstrap resamples and used to assess whether waist circumference mediated the association between birth weight and sedentary time. A significant indirect effect via the mediator between birth weight and sedentary time was determined if the 95% bCI did not overlap zero.

We did not have data on gestational age, and therefore, we could not differentiate between participants with low birth weight because of premature birth or growth restriction. The sample consisted of 553 participants who could be considered premature (birth weight <2.5 kg), and therefore, we performed sensitivity analyses by excluding participants with birth weight <2.5 kg.

We examined whether the association between birth weight and sedentary time was modified by sex or age by including the interaction term birth weight × sex and birth weight × age; however, no significant interactions were observed ($P > 0.10$). The association between different categories of birth weights and sedentary time is displayed graphically for illustrative purposes and presented as means and 95% CIs of the sedentary time for each birth weight group (see Results section). Birth weight was divided into 6 categories as follows: <2.75 kg (n = 1164), 2.75–3.25 kg (n = 2822), 3.26–3.75 kg (n = 4160), 3.76–4.25 kg (n = 2117), 4.26–4.75 kg (n = 449), and >4.75 kg (n = 81), and the birth-weight category 3.26–3.75 kg was chosen as the reference category because it contained the largest proportion of participants and in agreement with previous studies (10). All analyses were performed with SPSS v 18.0 software (SPSS).

RESULTS

Descriptive statistics by study and sex are summarized in **Tables 1** and **2**, respectively. Overall, 79.3% of children were categorized as normal weight, 15.9% of children were categorized as overweight, and 4.8% of children were categorized as obese. The mean birth weight differed by 0.33 kg between studies, and the lowest mean (±SD) birth weight (3.22 ± 0.54 kg) was observed from the cohort who represented a low- and middle-income country (Brazil). Children's sedentary time and physical activity were monitored for an average of 5.3 ± 1.3 d. Overall, the average time spent sedentary was 370 ± 91 min/d, whereas, on average, 56 ± 30 min/d were spent in MVPA. Boys spent, on average, significantly more time in MVPA than did girls (66 compared with 46 min/d, respectively; $P < 0.001$) and less time sedentary than did girls (360 compared with 380 min/d, respectively; $P < 0.001$).

Figure 1 shows the separate regression analyses conducted to assess each component of the proposed mediation model among variables. Birth weight was associated with sedentary time, and a 1-kg increase in birth weight was associated with 4 more minutes spent sedentary per day (c path; $B = 4.04$, $P = 0.006$). When this association was modeled graphically, the association seemed to be mainly driven by individuals in the extreme categories of birth weight (<2.75 and >4.75 kg) (**Figure 2**). In addition, birth weight was positively associated with waist circumference (a path; $B = 1.59$, $P < 0.001$), and waist circumference was positively associated with sedentary time (b path; $B = 0.82$, $P < 0.001$). Results of the mediation analysis confirmed the mediating role of waist circumference in the association between birth weight and sedentary time ($a \times b$ path; B: 1.30; 95% bCI: 0.94, 1.72). Furthermore, our results showed that the direct effect of birth weight on sedentary time was attenuated by 32% (c' path; $B = 2.74$, $P = 0.06$) when controlling for waist circumference, which suggested partial mediation.

In sensitivity analyses, with the exclusion of individuals with birth weight <2.5 kg, results were mainly unchanged. Birth weight was associated with sedentary time (c path; $B = 4.66$, $P = 0.01$) and waist circumference (a path; $B = 2.15$, $P < 0.001$), and waist circumference was positively associated with sedentary time (b path; $B = 0.81$, $P < 0.001$). In addition, results of the mediation analysis confirmed the mediating role of waist circumference in the association between birth weight and

TABLE 1

Descriptive statistics of the 8 included studies (n = 10,793)[1]

Study, country (reference)	Year	n (% boys)	Age,[2] y	Height, cm	Weight, kg	BMI,[3] kg/m^2	Birth weight, kg	Total physical activity, counts/min	Sedentary time,[4] min/d	MVPA,[5] min/d
ALSPAC, United Kingdom (32)	2003–2004	5808 (48)	11–15	151.8 ± 8.1[6]	44.4 ± 10.5	19.1 ± 3.4	3.41 ± 0.55	588 ± 191	371 ± 75	57 ± 28
EYHS, Denmark (31, 33)	1997–1998	1162 (45)	8–18	148.5 ± 15.3	41.8 ± 14.3	18.4 ± 3.1	3.40 ± 0.59	562 ± 253	384 ± 125	50 ± 33
EYHS, Estonia (31)	1998–1999	557 (44)	8–17	151.8 ± 17.1	44.0 ± 15.6	18.4 ± 3.1	3.55 ± 0.59	631 ± 251	352 ± 111	63 ± 38
EYHS, Norway (31, 40)	1999–2000	350 (51)	9–10	139.3 ± 6.3	33.3 ± 5.9	17.1 ± 2.3	3.46 ± 0.59	709 ± 305	339 ± 108	69 ± 37
EYHS, Portugal (31, 36)	1999–2000	547 (51)	9–18	147.1 ± 14.6	43.3 ± 14.4	19.5 ± 3.7	3.39 ± 0.52	553 ± 233	390 ± 109	52 ± 35
KISS, Switzerland (39)	2005; 2006	307 (46)	6–13	136.4 ± 13.0	33.0 ± 10.1	17.3 ± 2.8	3.36 ± 0.57	576 ± 212	307 ± 112	74 ± 30
Pelotas, Brazil (34, 35)	2006–2007	426 (53)	13–14	157.9 ± 8.4	50.9 ± 12.1	20.3 ± 3.8	3.22 ± 0.54	320 ± 118	389 ± 132	40 ± 26
SPEEDY, United Kingdom (37, 38)	2007	1636 (44)	10–11	141.1 ± 6.7	36.5 ± 8.3	18.2 ± 3.1	3.35 ± 0.58	594 ± 190	371 ± 69	50 ± 24

[1] ALSPAC, Avon Longitudinal Study of Parents and Children; EYHS, European Youth Heart Study; KISS, Kinder Sportstudie; MVPA, moderate-to-vigorous physical activity; SPEEDY, Sport, Physical Activity and Eating Behavior: Environmental Determinants in Young People.

[2] All values are ranges.

[3] BMI is calculated as weight divided by height squared.

[4] The cutoff for sedentary time was <100 counts/min.

[5] The cutoff for MVPA was >3000 counts/min.

[6] Mean ± SD (all such values).

TABLE 2
Baseline descriptive statistics of the sample stratified by sex (*n* = 10,793)

	Boys (*n* = 5092)	Girls (*n* = 5701)	*P*[1]
Age, y	11.5 ± 1.6[2]	11.5 ± 1.7	0.63
Weight, kg	42.0 ± 12.1	42.8 ± 11.6	0.001
Height, cm	149.1 ± 11.9	148.8 ± 10.7	0.13
Waist circumference, cm	66.7 ± 9.2	65.7 ± 9.2	<0.001
BMI[3,4]	18.6 ± 3.2	19.0 ± 3.4	<0.001
Normal weight,[3] *n* (%)	4109 (80.8)	4432 (77.9)	—
Overweight,[3] *n* (%)	767 (15.1)	946 (16.6)	—
Obese,[3] *n* (%)	207 (4.1)	312 (5.5)	—
Birth weight, g	3459 ± 584	3345 ± 535	<0.001
Total physical activity, counts/min	637 ± 231	528 ± 186	<0.001
Sedentary time,[5] min/d	360 ± 91	380 ± 90	<0.001
MVPA,[6] min/d	66 ± 33	46 ± 23	<0.001
Wear time, d	5.4 ± 1.4	5.3 ± 1.3	0.96

[1] *P* values denote differences between sex and were determined by using a *t* test for normally distributed continuous variables.

[2] Mean ± SD (all such values).

[3] *n* = 5083 and 5690 for boys and girls, respectively.

[4] Age- and sex-specific BMI cutoffs proposed by Cole et al. (45) were used.

[5] The cutoff for sedentary time was <100 counts/min.

[6] MVPA, moderate-to-vigorous physical activity. The cutoff for MVPA was >3000 counts/min.

sedentary time ($a \times b$ path; B: 1.74; 95% bCI: 1.26, 2.30) and supported partial mediation (c' path; $B = 2.92$, $P = 0.11$).

DISCUSSION

This study examined whether birth weight acts as a correlate of sedentary time in youth and whether this association is mediated by waist circumference. The results suggested that the association between birth weight and sedentary time was partially mediated by waist circumference in young people aged 6–18 y.

We proposed that central adiposity could be an underlying mechanism of the association between birth weight and sedentary time for several reasons. Birth weight appears to be associated with several measures of adiposity (15, 17, 19), muscle mass (6), and aerobic fitness later in life (9), which are factors that are potentially related to sedentary time. In addition, obesity has been related to aerobic fitness, muscle mass (20), and objectively measured sedentary time in youth (21). Our participants covered a wide range of the birth-weight spectrum (645–5750 g), and even though we showed significant differences in weight and birth weight between sexes, differences were small (<0.8 kg or 115 g) and may not have been clinically important. The results showed that the association was partially mediated by waist circumference, and the effect of birth weight on sedentary time was reduced by 32% when controlling for the suggested mediator. In addition, controlling for waist circumference made the association between birth weight and sedentary time nonsignificant. This result could have been due to multicollinearity between birth weight and waist circumference, and with a larger sample size, this result could have reached significance. However, when the significance was disregarded, the magnitude of the association was small, and a 1-kg increase in birth weight was associated with only 2.7 more minutes spent sedentary per day. This observation was opposite to some previous observations in animal models (11, 12) but consistent with the results of a previous study in subjects born with low to normal birth weights; these results were also unable to show an association between birth weight and sedentary time (13). Although sedentary behavior is different from not performing enough physical activity (49), studies that used objectively measured physical activity were also unable to show an association between birth weight and later levels of physical activity in youth (13, 50–53), and it has been suggested that, across the normal birth weight spectrum, physical activity and sedentary time in youth are more influenced by environmental and behavioral factors than birth weight (50). In contrast, the magnitude of the association between birth weight and sedentary time (and physical activity) could have been underestimated because of the inherent variability of youth's sedentary time and physical activity. A few days of measurement may not have been representative of the true durations of sedentary time in our participants (54, 55). It is also unknown whether the magnitude of the association between birth weight and sedentary time changes by age and may become apparent in adulthood.

A limitation regarding the mediating role of abdominal adiposity in the current study was that waist circumference was measured at the same point in time as sedentary time. Thus, the temporal sequence between waist circumference and sedentary

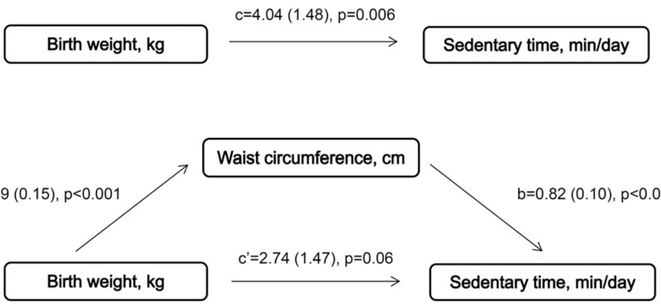

FIGURE 1 Unstandardized regression coefficients (±SEs) in regression analyses included in the mediator model between birth weight, waist circumference, and sedentary time (*n* = 10,793). Analyses were performed by using ordinary least-squares regression and adjusted for sex, age, study, and monitor wear time. The paths represent the difference in waist circumference (cm) per 1-kg increase in birth weight (path a), difference in sedentary time (min/d) per 1-cm increase in waist circumference (path b), and differences in sedentary time (min/d) per 1-kg increase in birth weight with (path c′) and without (path c) adjustment for waist circumference.

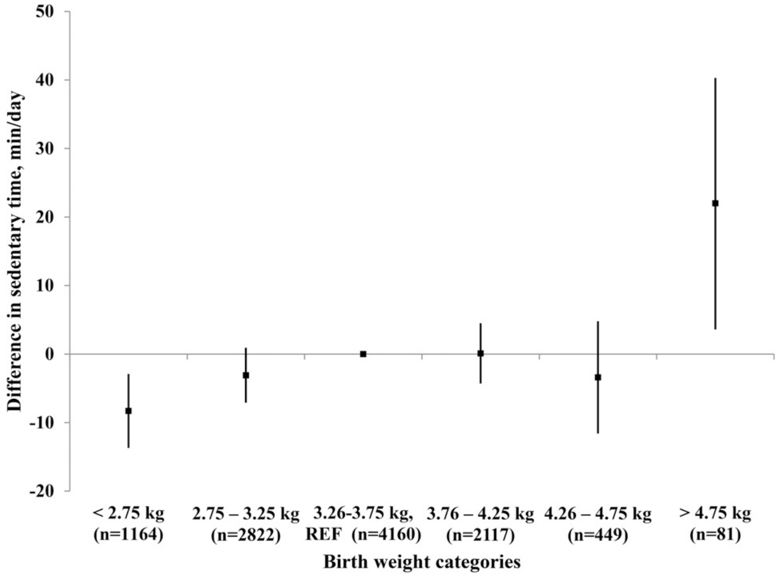

FIGURE 2 Mean (95% CI) differences expressed in sedentary min/d stratified by birth-weight categories compared with the reference group (birth weight: 3.26–3.75 kg; n = 10,793; P-trend = 0.003) adjusted for sex, age, study, and monitor wear time (ordinary least-squares regression). REF, reference.

time was not possible to establish. However, it was previously shown that higher waist circumference predicted higher amounts of sedentary time in youth (21, 23), whereas sedentary time did not predict adiposity (21–23, 56–58). In addition, a re-analysis of the data modeling sedentary time as the mediator and waist circumference as the outcome showed that, although significant, sedentary time attenuated the effect of birth weight on waist circumference by only 2% (compared with 32% when waist circumference was the mediator; data not shown), which supported the use of waist circumference as a mediator in our analyses. Nevertheless, our results did not dismiss the possibility of a reverse causation (i.e., a bidirectional association between sedentary time and abdominal adiposity).

Previous studies showed that lower birth weight is associated with central adipose tissue in childhood (16, 18, 19). In the current study, higher birth weight was associated with higher waist circumference; however, this association was attenuated by current BMI (results not shown). The interpretation of associations between birth weight and obesity later in life, which were substantially attenuated after adjustment for current body size (e.g., BMI), suggested that postnatal growth and the change in size (e.g., weight percentile crossing) between time points may be more-important factors on the causal pathway leading to abdominal adiposity than birth weight per se (59). As a result, public health strategies intended to influence the biology of fetal growth are most likely not the most essential approaches, maybe with the exception for obese pregnant women and those who have gestational diabetes, because both obesity during pregnancy and gestational diabetes are associated with large-for-gestational-age infants (60, 61). Rather, strategies that aim to affect other factors such as postnatal weight gain are likely to be more successful to moderate risk of obesity and metabolic diseases later in life because rapid infant weight is associated with childhood obesity (62).

There were several strengths of this study, including objectively measured sedentary time, a wide range of birth weights, and a large and diverse sample representing different geographical and cultural locations. Even though accelerometer data were re-analyzed in a standardized manner, and all analyses were adjusted for wear time, it was possible that differences in accelerometer wear protocol influenced the results. One of the included studies used a 24-h monitor wear protocol, and even if this difference was accounted for by excluding time between 2400 and 0700, this protocol may have influenced the amount of time defined as sedentary time in this specific study. However, when the data were re-analyzed after the exclusion of this study, findings were largely unchanged (data not shown).

There were some limitations that warrant consideration in interpreting the results of the current study. The accelerometer is regarded as a valid tool for measuring physical activity and sedentary time (43, 63); however, a hip-placed monitor can be less effective in distinguishing sedentary postures, such as lying and sitting, from other light-intensity activities performed while standing and do not accurately capture upper-body movement, cycling (64), or other activities when the monitor is removed (e.g., water-based activities). Finally, nonwear time was subtracted from wear time and, consequently, prolonged quiet sitting could potentially have been considered nonwear time, thereby leading to an underestimation of sedentary time. The amount of time spent sedentary may have differed between weekdays and weekend days. However, >85% of participants in our data set had ≥1 d of valid accelerometer data during a weekend day, and therefore, we believe it was unlikely that this difference affected our analyses of associations between birth weight and sedentary time. With the exception of one study, birth weight was reported retrospectively. However, it has been suggested that maternally recalled birth weight is highly correlated with measured birth weight and is sufficiently accurate to use in epidemiologic studies (47). Waist circumference was used as the outcome for abdominal adiposity. Despite abdominal adiposity being recognized as an important determinant for disease and mortality (65), a more-detailed measure of body composition may be preferred. Finally, we could not exclude that other unmeasured confounding variables including genotype, infant rapid weight gain, socioeconomic status, and mothers' BMI might explain our findings. Future prospective studies with several measures of the mentioned confounder variables are needed to examine the potential mediating or modifying effects on the relation between birth weight and later sedentary time at different ages.

In conclusion, the prevalence of sedentary time in youth is of public health concern, and therefore, it is important to understand potential biological and behavioral correlates of this behavior. The results suggest that birth weight is positively associated with sedentary time; however, the association appears partially mediated by central adiposity. Therefore, the targeting of both birth weight and obesity may be an important public health strategy to prevent excessive sedentary time in youth.

ICAD Collaborators include the ICAD Steering Committee [Ashley Cooper and Angie Page (Bristol University, Bristol, United Kingdom), Ulf Ekelund (Norwegian School of Sport Sciences, Oslo, Norway), Dale Esliger and Lauren B Sherar (Loughborough University, Loughborough, United Kingdom), and Esther MF van Sluijs (Medical Research Council Epidemiology Unit, University of Cambridge, Cambridge, United Kingdom)] and the following ICAD data contributors—the Avon Longitudinal Study of Parents and Children: K Kordas; the BALLABEINA Study: J Puder; the Belgium Pre-School Study: G Cardon; the Children's Health and Activity Monitoring for Schools United Kingdom: C Gidlow and R Davey; the Children Living in Active Neigbourhoods and Healthy Eating and Play Study: J Salmon; the Copenhagen School Child Intervention Study: LB Andersen; the European Youth Heart Study Denmark: K Froberg; the European Youth Heart Study Norway: SA Anderssen; the European Youth Heart Study Portugal: LB Sardinha; the Iowa Bone Development Study: KF Janz; the Kinder-Sportstudie: S Kriemler: the Movement and Activity Glasgow Intervention in Children: J Reilly; the NHANES: R Troiano and M McDowell; the Personal and Environmental Associations with Children's Health: A Cooper; the Pelotas Birth Cohort: P Hallal; the Sport, Physical Activity and Eating Behavior: Environmental Determinants in Young People: E van Sluijs; and the Physical Activity in Preschool Children and Project Trial of Activity for Adolescent Girls and Children's Health and Activity Monitoring for Schools US: R Pate. We also immensely thank Chris Riddoch, Ken Judge, and Pippa Griew for their original involvement in the ICAD.

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Errata

Erratum for Hildebrand et al. Association between birth weight and objectively measured sedentary time is mediated by central adiposity: data in 10,793 youth from the International Children's Accelerometry Database. Am J Clin Nutr 2015;101:983–90.

The phrase "on behalf of the International Children's Accelerometry Database (ICAD) Collaborators" was erroneously removed from the author list. The author line of the article should read as follows: Maria Hildebrand, Elin Kolle, Bjørge H Hansen, Paul J Collings, Katrien Wijndaele, Katarzyna Kordas, Ashley R Cooper, Lauren B Sherar, Lars Bo Andersen, Luis B Sardinha, Susi Kriemler, Pedro Hallal, Esther van Sluijs, and Ulf Ekelund on behalf of the International Children's Accelerometry Database (ICAD) Collaborators.

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Paper IV

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REVIEW Open Access

Prenatal, birth and early life predictors of sedentary behavior in young people: a systematic review

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Abstract

Background: Our aim was to systematically summarize the evidence on whether prenatal, birth and early life factors up to 6 years of age predict sedentary behavior in young people (≤18 years).

Methods: PRISMA guidelines were followed, and searches were conducted in PubMed, SPORTDiscus, EMBASE and Web of Science up to December 1, 2015. We included observational (non-intervention) and longitudinal studies, that reported data on the association between one or more of the potential predictors and objectively or subjectively measured sedentary behavior. Study quality was assessed using a formal checklist and data extraction was performed using standardized forms independently by two researchers.

Results: More than 18,000 articles were screened, and 16 studies, examining 10 different predictors, were included. Study quality was variable (0.36-0.95). Two studies suggest that heritability and BMI in children aged 2–6 years were significant predictors of sedentary behavior later in life, while four and seven studies suggest no evidence for an association between gestational age, birth weight and sedentary behavior respectively. There was insufficient evidence whether other prenatal, birth and early life factors act as predictors of later sedentary behavior in young people.

Conclusion: The results suggest that heritability and early childhood BMI may predict sedentary behavior in young people. However, small number of studies included and methodological limitations, including subjective and poorly validated sedentary behavior assessment, limits the conclusions.

Trial registration: The systematic review is registered in the International Prospective Register of Systematic Reviews, PROSPERO, 17.10.2014 (CRD42014014156).

Keywords: Sedentary behavior, Youth, Children, Determinants, Early life, Prenatal

Background

Sedentary behavior, defined as a distinct class of waking behavior in a seated or reclining posture that requires an energy expenditure ≤1.5 METs [1], is highly prevalent in contemporary youth [2–4]. For example, studies using objective measures of sedentary time estimate that 41 to 78 % of awake time is spent sedentary in young people aged 7–15 years old [5]. Further, high amounts of sedentary behavior may be associated with adverse health outcomes [6–9], and to be able to implement effective interventions and inform policy, increased knowledge about predictors and determinants of sedentary behavior are needed. Previous systematic reviews have mainly focused on environmental, social, behavioral and policy factors during childhood and adolescence (>6 years of age) as determinants of later sedentary behavior [10, 11]. However, studies have shown that high amounts of sedentary time are present already in younger children (3–5 years of age) [12], that this behavior increases during childhood [13, 14] and tracks from childhood to adolescent and adulthood [15], suggesting that important factors associated with sedentary behavior may manifest early in life, perhaps already during the fetal period or at birth.

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According to the Developmental Origins of Health and Disease hypothesis, non-optimal growth and environmental conditions during fetal life and early childhood may result in permanent changes in the body's structure, function and metabolism [16]. These adaptations, potentially caused by epigenetics [16] and irreversible, may lead to increased risk of diseases and an altered behavior later in life. For example, birth weight, which is used as a marker of intrauterine growth and the intra-uterine environment, is broadly inversely associated with the risk of cardiovascular disease [17, 18], type 2 diabetes [19, 20], and all-cause mortality [21, 22]. Furthermore, results from animal studies suggest that the offspring of undernourished mothers are less active and more sedentary compared with normal offspring [23, 24], and the underlying mechanism for this association might be due to remodeling of the hypothalamus through alterations in availability of nutrients or hormonal signaling [23]. Another possible hypothetical pathway between prenatal, birth and early life factors, that are usually categorized as physical factors [25], and sedentary behavior might be through excessive adiposity tissue. High and low birth weights [26–30], genetics [31], maternal physical activity during pregnancy [32] and early rapid weight gain [33–35] are all predictors of later obesity, which might constrain physical movement [36] and lead to a sedentary lifestyle [37–39]. Moreover, these putative underlying physical factors acting during gestation, at birth and in early life may, directly or indirectly, predict sedentary behavior through a variety of other biological mechanisms, including reduced aerobic fitness [40], lower muscle strength [41], decreased lung function [42] and genetic abnormality [43].

Therefore, the aim of this study was to examine whether prenatal, birth and early life physical factors (up to 3–6 years of age) are predictors of sedentary behavior by synthesizing the evidence from observational research in young people ≤ 18 years old.

Methods

Study inclusion criteria

The review is registered in PROSPERO CRD42014014156, and follows the PRISMA guidelines. The review aimed to identify all observational (non-intervention) longitudinal studies (prospective and retrospective) reporting data on the association between one or more of the potential predictors and sedentary behavior in young people (aged ≤18 years). Only studies that examined factors which may be causally associated with the outcome (factors that precedes sedentary behavior later in life), rather than correlates (factors which are statistically associated with the outcome in cross-sectional analyses), were included. The term "determinant" is often used in similar studies [10, 11], however since evidence from observational studies does not prove cause-and-effect relationship [44], we here use the term "predictor".

We adopted the following inclusion criteria: (i) written in English (ii) published after 01/01/2000; (iii) published as journal articles or reports; and (iv) including healthy children. Thus, studies only including a specific group (e.g., only obese or children with premature birth) were excluded from this review. The potential predictors were identified as prenatal, birth and early life characteristics, previously classified under the physical domain [25, 45] when studied in relation to physical activity [46, 47] (Fig. 1). We have defined early life from birth to three years of age since motor development up to three years of age is characterised by achieving fundamental developmental milestones, e.g., sit with and without support, supported and unsupported standing and walking [48], while temperament, referring to biologically based individual differences in emotional, motor, and attentional reactivity, may interact with the environment over time

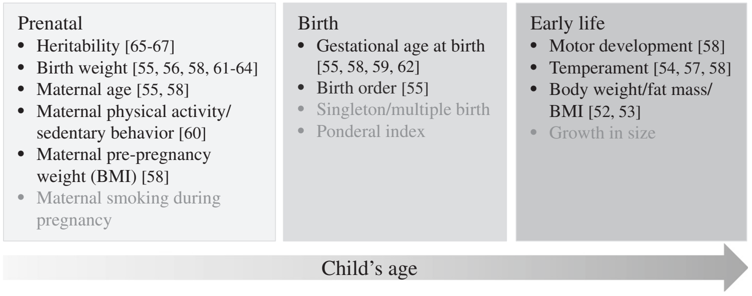

Fig. 1 Potential prenatal, birth and early life predictors of sedentary behavior included in the current review. References of included studies in squared brackets

[49]. To take into account potentially critical periods such as the adiposity rebound [50] when considering growth and body size (body weight/fat mass/body mass index, BMI), we included studies examining these factors between birth and 6 years of age. In addition, gene variants may influence on the in utero development [31], and was therefore explored as a potential predictor.

Sedentary behavior includes activities such as watching television, using a computer or sitting at school. Studies were included if they measured total sedentary time (e.g., minutes/day) or a specific type of sedentary behaviors (e.g., TV-viewing, computer use etc.), measured either objectively (e.g., with an accelerometer) or subjectively (e.g., with self- or parentally reported questionnaires).

Search strategy

Two researchers performed a systematic literature search in the electronic databases PubMed, SPORTDiscus, EMBASE and Web of Science including studies published between January 2000 and December 1, 2015 (Fig. 2). The searches included terms related to sedentary behavior (sedentary time, TV-viewing, etc.) in combination with the sample of interest (children, youth, adolescent etc.) and terms related to the potential predictors (birth weight, motor development etc.). An additional file shows a detailed overview of the search strategy [see Additional file 1].

Identified articles were imported to Reference Manager Professional Edition (version 12, Thomson Reuters, San Francisco, CA, USA) and duplicates were removed. One researcher screened the titles, whereas two researchers independently screened all abstracts to minimize the risk of elimination of eligible studies by mistake. If any doubts the articles were included to the next phase. Two researchers independently performed the full-text review. The reference lists of all included studies were reviewed (backward tracking), and a citation search was performed in the database Web of Science (forward tracking). In addition, all reviewers manually searched through personal reference databases.

Data extraction and statistical analysis

Data were extracted using standardized forms independently by two researchers. Any disagreements were resolved by consensus or by a third researcher. We extracted the following data; study characteristics (title, author, year, study design, country, number of participants, subject characteristics, year of baseline measure and year of follow-up), predictors examined and assessment method, sedentary behavior and assessment

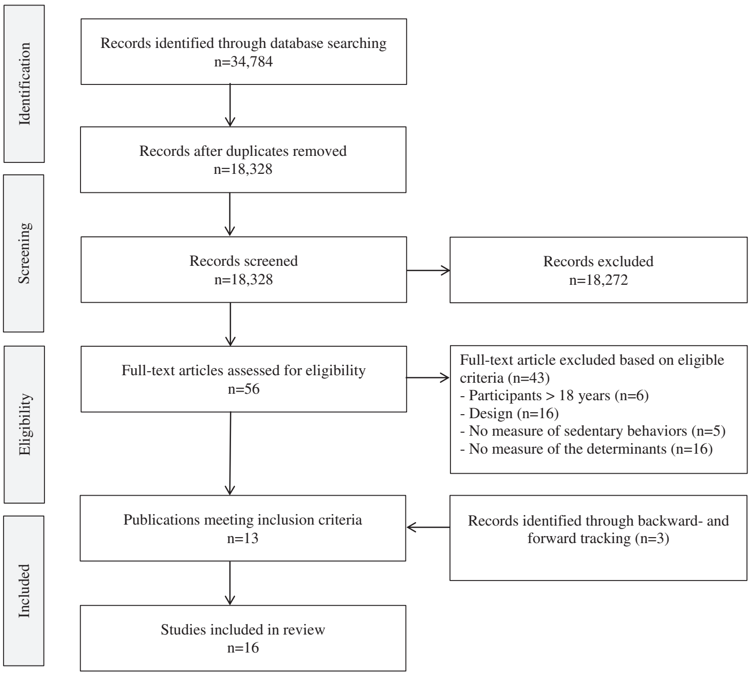

Fig. 2 Flow diagram of review process

method, statistics and analysis, main results and results stratified by sub-groups if provided in the article (e.g., sex and age-groups). Researchers were not blinded to the authors or journals when extracting data.

The primary aim was to synthesize the evidence by formal meta-analyses on the association between the predictors and sedentary behavior. However due to few studies retrieved, and heterogeneity in the exposure and outcome measures in these studies, this was not possible. Therefore, the data were synthesized narratively.

Quality assessment

Quality assessment of the included studies was performed using a formal checklist [51]. Two independent researchers performed the quality assessment, and any disagreements where resolved by consensus or by consultation with a third researcher if necessary. Studies were given scores (0- No, 1- Partial, 2-Yes) on 11 items based on the degree to which the criteria were met [Additional file 2]. For each study, a summary score was calculated as the sum of scores from each item divided by the highest possible score. Study quality scores therefore ranged from 0–1, where a higher score corresponds to higher quality. The result of the quality assessment was used for discussion of the quality of the studies and no study was excluded based on this assessment.

Results

The database searches resulted in more than 34,000 potentially relevant articles, but after removal of duplicates approximately 18,300 articles remained. Details of the search and screening process are shown in Fig. 2. The title and abstract review resulted in the retrieval of 56 full-text articles, which were reviewed in detail. Of these, 13 studies met the criteria for study inclusion. The backward- and forward tracking process of the included studies resulted in additional three identified studies meeting our inclusion criteria. In total, 16 unique studies including ten potential predictors were included (Fig. 1). Individual study characteristics, in addition to the main results showing the association between the predictors and sedentary behavior are presented in Table 1.

Study characteristics

Of the 16 included studies, eight were longitudinal prospective birth cohorts [52–59], while three studies had retrospective data collection [60–62], and two studies included a combination of both prospective and retrospective measures [63, 64]. Three studies examining heritability of sedentary behavior were cross-sectional twin studies [65, 66] or twin-family studies (i.e., including both twins and a non-twin siblings) [67]. The majority of the studies were conducted in the USA (*n* = 5) [54, 57, 60, 61, 65], UK (*n* = 5) [55, 59, 63, 64, 66], or Australia (*n* = 3) [52, 53, 56]. All studies were published from 2010 and onwards, with five studies being published during 2014 and 2015 [57, 59, 60, 63, 65]. The sample sizes ranged from 20 [60] to 10,793 participants [63]. Eight studies measured sedentary time objectively [55, 58–61, 63, 64, 66], while the remaining studies used subjective methods, including self-reported screen time [56, 67], parent-reported TV-time [52–54, 57, 62], or a summary of time spent watching TV, sitting doing nothing and sitting listening to music [65]. The included age groups at follow-up were 0–6 years (*n* = 4) [54, 57, 58, 61], 7–12 years (*n* = 5) [52, 55, 60, 62, 66], or a combination of different age groups ≤18 years (*n* = 7) [53, 56, 59, 63–65, 67].

Quality assessment

The included articles had a quality score between 0.36 and 0.95 (range 0 – 1) (Table 1), and 11 studies had a score above 0.80. The most common limitation was the use of a subjective and poorly validated measure of the outcome (*n* = 8), such as parentally reported TV-viewing. Other limitations include incomplete description of participant selection (*n* = 8), incomplete participant characteristics (*n* = 6), variance estimates not provided for all results (*n* = 7), lack of controlling for several confounding variables (*n* = 5) and insufficient reporting of results (*n* = 4).

Prenatal predictors and sedentary behavior

No studies were identified that examined whether maternal smoking or maternal sedentary behavior during pregnancy act as predictors of sedentary behavior in the offspring. Based on a limited number of studies, there was no evidence for an association between maternal pre-pregnancy weight [58] and maternal physical activity during pregnancy [60] and objectively measured sedentary time in children aged 2 and 8–10 years. Similarly, no association between maternal age at birth and objectively measured sedentary time in children aged 2 or 8–10 years [55, 58] was observed.

Two studies found that heritability was a significant contributor on self-reported leisure sedentary time/screen time in children aged 12 years or older [65, 67]. One of these studies reported higher heritability in girls (girls versus boys: 30 % versus 9 %) [65], while another reported the opposite (19 % versus 35 %) [67]. Finally, one study observed a borderline none significant heritability effect on the variance in objectively measured sedentary time in 9-12-year-old children [66].

Seven studies examined the association between birth weight and sedentary behavior. Based on five studies, there is no evidence for an associations between birth weight and objectively measured sedentary time [55, 58, 61], total recreational screen time [56] or increased risk of TV-viewing ≥ 2 h per day [62]. One study presented data using

Table 1 Individual study characteristics and results showing the relation (and direction) between the included predictors and sedentary behavior in young people

First author (year)	Country	Age, baseline (years)	Mean age (SD), follow-up (years)	n (% girls)	Assessment of sedentary behavior	Predictors and association with sedentary behavior										Quality assessment
						Heritability	Maternal age	Maternal PA	Maternal pre-pregnancy weight	Birth weight	Gestational age	Birth order	Motor development	Temperament	BMI	
Fisher (2010) [66]	UK		11.2 (0.5)	234 (54)	Acc	0										0.91
Haberstick (2014) [65]	USA		15.1 (2.2)	2,847 (52)	Self-report[a]	+										0.77
van der Aa (2012) [67]	NED		15.9 (1.6)	6,011 (56)	Self-report SCT	+										0.86
Pearce (2012) [55]	UK	0	8-10 (range)	482 (52)	Acc		0			0	0	0				0.73
Wijtzes (2013) [58]	NED	0-1	2.1 (0.1)	347 (48)	Acc		0		0	0	0		0	0		0.82
Pivarnik (2014) [60]	USA		8-10 (range)	20	Acc			0								0.36
Byun (2011) [61]	USA		4.3 (0.6)	331 (49)	Acc					0						0.95
Gopinath (2013) [56]	AUS		12.7 (0.4) 17-18 (range)	1,794 (50) 752 (53)	Self-report SCT					0						0.82
Hildebrand (2015) [63]	ICAD[b]		6-18 (range)	10,793 (53)	Acc					0						0.95
Peneau (2011) [62]	FRA		7-9 (range)	2,207 (49)	Parent-report TV					0	0					0.82
Ridgway (2011) [64]	Overall[c] EYHS[d] UK UK BRA	0	12.0 (2.9) 14.5 (0.5) 10.2 (0.3) 13.3 (0.3)	4170 1,240 (53) 811 (56) 1,647 (56) 472 (48)	Acc Acc Acc Acc					0 0 - 0 0						0.95
Lowe (2015) [59]	UK	0	11 15	5327 (52) 1947 (55)	Acc						0					0.86
Thompson (2013) [54]	USA	3m-1	1.5	110-217	Parent-report TV									+/0		0.86
Radesky (2014) [57]	USA	9m	2.0	7450 (49)	Parent-report TV									+		0.91

Table 1 Individual study characteristics and results showing the relation (and direction) between the included predictors and sedentary behavior in young people *(Continued)*

Fuller-Tyszkiewicz (2012) [52]	AUS	2.3 6.3	4.3 (0.4) 6.3 (0.5) 8.3 (0.4) 10.3 (0.5)	4,724 (49) 4,340 (49)	Parent-report TV	+	0.64
Hands (2011) [53]	AUS	6	8.1 (0.4)	1,271 (49)	Parent-report TV	+	0.77

0, no association; +, positive association; -, negative association

Acc accelerometer, *AUS* Australia, *BRA* Brazil, *FRA* France, *M* months, *NED* Netherlands, *PA* physical activity, *TV* time TV-viewing, *SCT* screen time, *R* retrospectively

[a] Include hours watching TV, sitting doing nothing and sitting listening to music per week. [b]Data from eight studies in the International Children's Accelerometry Database (ICAD) collected in United Kingdom, Denmark, Estonia, Norway, Portugal, Switzerland and Brazil. [c]Data presented as overall from the meta-analysis and for each study included in the meta-analysis. [d]Data from the European Youth Heart Study (EYHS) collected in Norway, Portugal, Estonia and Denmark

a combined meta-analysis from four cohorts, and observed no evidence for an association between birth weight and objectively measured sedentary time [64]. However in study specific analyses, a low birth weight was associated with higher amounts of sedentary time in one of the studies (the Roots-study, $n = 811$), whereas a high birth weight was associated with higher amounts of sedentary time in another (The Pelotas Birth Cohort, $n = 472$). The latter study was the only study in which gestational age was assessed, and after adjusting for this covariate, the positive association was no longer significant [64]. Finally, the seventh study used pooled data from eight studies ($n = 10{,}793$) and found that high birth weight was associated with greater amount of time spent sedentary, however this association was partly mediated by waist circumference [63].

Birth predictors and sedentary behavior

We did not identify any study examining whether ponderal index at birth was associated with subsequent sedentary behavior. One study found no evidence for an association between birth order and objectively measured sedentary time in 8 to 10-year-olds [55].

There was no evidence for an association between gestational age and objectively measured sedentary time in 8 to 10-year-olds [55], or TV-viewing ≥ 2 h per day in 7-9-year-olds [62]. In addition, preterm birth (<37 weeks gestation) was not associated with increased sedentary time in children aged 2, 11 and 15 years in comparison with full term birth [58, 59].

Early life predictors and sedentary behavior

We did not identify any study examining whether infant and childhood growth patterns predict later sedentary behavior, however two studies examined the association between BMI and later sedentary behavior. It appears that BMI measured in children aged 2–6 years old positively predicts TV-viewing two or several years later [52, 53], however dietary intake mediated the relationship for the older children in one of the studies [52].

Inconsistent evidence was observed for the association between early life temperament and sedentary behavior. Among infants and toddlers, two studies found a positive association between crying duration (hours/day) [54] and having problems with self-regulation (i.e., sleep, mood and behavior regulation and attention) [57] and viewing TV/video. In contrast, no association was found between two other dimensions of infant and toddlerhood temperament (i.e., activity level such as arm and leg movements, squirming etc. and fussiness) and objectively measured sedentary time/TV-exposure in children aged 1.5-2 years [54, 58].

One study showed no association between having a delayed gross motor development at 1 year and sedentary time in 2-year-old children [58].

Discussion

We have systematically summarized the existing knowledge on potential prenatal, birth and early life predictors of sedentary behavior in young people. Few studies have examined whether these factors act as predictors of sedentary behavior later in life. However, the results suggest that heritability and childhood body weight (≤6 years) may be possible predictors of later sedentary behavior, while birth weight and gestational age are unlikely important predictors of this behavior.

Prenatal factors

Maternal age at birth, maternal pre-pregnancy weight and maternal physical activity during pregnancy were not related to sedentary behavior in the offspring [55, 58, 60]. However, it is difficult to distinguish between the potential biological effects that may occur during fetal life due to maternal age (e.g., young mothers who are still growing might be competing for nutrients with the fetus, or higher maternal age could influence genetic abnormality [43]), and other non-biological differences later in life (e.g., behavior, education, socioeconomic status). Due to the low number of studies, of which one was categorized as low quality, it is not possible to draw any firm conclusions of whether maternal factors during pregnancy may influence later sedentary behavior in their offspring. Additional studies including high quality, objective measures of physical activity and sedentary time in women before and during pregnancy are needed to examine whether these behaviors may transmit to their offspring.

Data from twin studies comparing differences in agreement between monozygotic and dizygotic twins are useful to estimate heritability or the genetic contribution to a given trait, e.g., sedentary behavior. If a monozygotic twin pair is more similar than a dizygotic twin pair, this suggests heritability, whereas the remaining variance is due to environmental influences [68]. Two studies suggest heritability of variation in self-reported sedentary behavior, however one study reported higher heritability among girls [65], and the other among boys. This difference may be explained by different definitions of sedentary behavior. While one study included time spent on computer and video games [67], which may be more common activities in adolescent boys than girls, this was not included in the other study [65]. The third study examining whether heritability influenced sedentary behavior found a borderline-significant association with objectively measured sedentary time in younger children [66], however a small sample size, and a younger age group (9–12 years) may explain the non-significant associations. It can be assumed that younger children are more influenced by non-heritable factors such as parents and the school environment than older children are. This hypothesis is supported by one study showing an increased genetic contribution with increased age [67], and further supported by studies in adults in which the heritability of sedentary behaviors appears greater in magnitude than in young people (>30 %) [69–71]. Additional studies are needed to identify regions within a genome contributing to variation in sedentary behavior [71]. While no robust genetic markers for this behavior have been identified through genome wide association studies, a linkage between objectively measured sedentary time, and two markers (D18S1102, D18S64) on chromosome 18 in overweight and obese youth has been observed [72].

The possible mechanisms for an association between birth weight and subsequent sedentary behavior are not clear. However a low birth weight is associated with lower muscle mass, strength [41, 73] and aerobic fitness later in life [40, 74], and both low and high birth weights are associated with several measures of adiposity [26–30]; factors that may be related to sedentary behavior. In adjusted analysis, only one study observed a positive association between birth weight and sedentary time, however this was partly mediated by abdominal adiposity [63]. The remaining six studies found no evidence for a relationship with objectively [55, 58, 61, 64] and subjectively measured sedentary behavior [56, 62]. Although five studies used an objective measure for sedentary time, a formal meta-analysis was not possible due to several reasons. First, sedentary time was expressed in diverse metrics (e.g., % sedentary time vs. minutes of sedentary time per day) and different thresholds were used to define time spent sedentary. Secondly, one study [63] is considerably larger compared to the others (Table 1) and would substantially influence the result of a formal meta-analysis. Finally, a meta-analysis of few studies with low methodological quality and heterogeneity in study design, participants and measurements is not recommended since it can lead to misleading results and interpretations [75]. Based on the results from the available literature, birth weight is not an important predictor for sedentary behavior in children and youth, and if such association is observed it may be explained by a positive association between higher birth weight and adiposity [63]. These observations are in agreement with a recent meta-analysis in children and youth, on the association between birth weight and physical activity [76].

Factors related to birth

Previous studies suggest that being born preterm is associated with decreased lung function, which persists as a degree of functional impairment through life [42, 77]. Therefore, children born preterm might be more sedentary compared to children born at term. We identified four studies all suggesting that gestational age is not associated with sedentary behavior in young people [55, 58, 59, 62], despite the fact that one study showed that preterm-born children had lung function deficits earlier in childhood [59]. The results are further supported by studies showing no association between preterm birth and objectively measured physical activity in children [59] and adults [78]. Children born preterm are often encouraged to be physically active, in order to promote their health. This may therefore negate any tendency for preterm children to be less active than their term born peers.

Early childhood factors

Early motor development has been associated with higher physical activity in childhood [47, 76] and it is plausible that infants and children who experience later or impaired motor development automatically choose to be more sedentary. Higher motor coordination (i.e., ball throwing, one-foot balance and walking backwards) at age 10 years have been associated with less screen time in adolescence and adulthood [79]. However, we did only identify one, relatively small study, suggesting no association between a delayed early life motor development and objectively measured sedentary time in toddlers [58]. Therefore, studies with larger sample sizes and longer duration of follow-up are warranted to examine whether impaired motor development acts as a predictor of sedentary behavior, and whether this association is modifiable [80].

Infant temperament has been associated with the risk for development of overweight and obesity in children [81] and it has been suggested that infants and toddlers scoring higher on selected dimensions of temperament (e.g., sad, aggressive, active) are more likely to be given an obesogenic diet by their caregivers [82–85]. It is also plausible that the TV can be used to sooth and entertain children who are perceived as more aggressive and difficult to calm. Two studies suggested both positive [54, 57] and no association [54] between early life temperament and parent-reported TV time, and the latter is supported by one study using objectively measured sedentary behavior [58]. Explanation for the mixed results may be explained by the assessment of different dimensions of infant temperament, and diversity between studies. The studies using parent-reported TV time suggest that the associations were stronger among mothers with low socioeconomic status [54, 57], and in overweight or obese mothers [54]. Hence, it seems as strategies aimed at educating low income and often overweight mothers in other ways to cope with challenging temperament traits in their children rather than using the TV, may be an important intervention to reduce the development of not only sedentary behavior, but also overweight and obesity among these children.

Both infancy and childhood rapid weight gain are independent risk factors for later obesity [34, 86], and possibly predictors of sedentary behavior since higher adiposity at one point appear to predict sedentary time later in childhood [87, 88]. While infant adiposity has been associated with lower activity level later in infancy [89], we did not identify any study examining the association between early rapid weight gain and sedentary behavior. However, two studies suggested that a higher BMI in 2-6-year-olds was associated with greater time spent sedentary later in life [52, 53]. This association is also observed longitudinally in older children [37], and supports the notion that sedentary behavior may be the result of overweight and obesity. However, the reason why higher levels of adiposity may predict higher amounts of sedentary time is not known. Explanations such as musculoskeletal pain [36], negative body image [90], bullying [90], and physiological limitations including impaired mitochondrial function [91] and insulin resistance [92] have been suggested, but further research is needed to obtain a better understanding of the underlying mechanisms.

Methodological issues

Strengths of this review included a comprehensive search strategy, the use of a standardized protocol, an up to date search including papers published until December 2015, and the inclusion of several potential predictors for sedentary behavior. As with any systematic review the methodological quality is no better than the studies included in the review. The main limitations with the review are the small number of retrieved studies, heterogeneous data and methodological quality in the included studies. Despite the large number of high quality birth cohorts available globally, few have included measures of sedentary behavior aimed at examining early life predictors of these behaviors. Eight out of 16 studies included in this review assessed sedentary time objectively by accelerometry. While a hip-placed accelerometer can provide sedentary data over a prolonged period, they are less valid in distinguishing sedentary postures, such as lying or sitting, from other light-intensity activities performed while standing [93]. In addition, different definitions of sedentary time and different data reductions methods may explain some of the dissimilarity in the results. Furthermore, the variability in time spent sedentary in children and adolescents is large, and only few days of measurement may not be representative of the true levels of time spent sedentary [94, 95]. Finally, specific environments (e.g., school) may reduce the between individual variability in sedentary time [96], and since young people spend most of their day at school, it is possible that accelerometer measurements during awake time will limit the possibility to detect associations with predicting factors. On the other hand, the ActivityStat hypothesis suggest that when physical activity is increased or decreased at one time, there will be a compensatory change at another time [97], so whether this issue has a large impact on the results is uncertain."

The majority of the studies assessing sedentary behavior by self-report did not provide information about the validity and reliability of the measurement. Several of the identified studies included relatively small sample sizes and may not be adequately powered to identify weak, but true associations. The majority of the studies examined children aged 11 years or younger, and it is unknown whether the magnitude of the association between the examined predictors and sedentary behavior changes by age and may become apparent later in life. Another limitation is the reliability of prenatal factors such as birth weight. Several studies used data from birth records or parentally reported at birth, which should provide accurate measurements, however some studies assessed birth weight retrospectively from the parents, which may be prone to misclassification. Finally, our aim was to examine physical factors that may be causally associated with the outcome, rather than those correlated with sedentary behavior. The included studies examined prenatal, birth and infancy factors that precedes sedentary behavior later in life, and several of the included studies were prospective in design, thereby allowing determination of the direction of associations. However, an observational study design does not provide proof of causation per se. Additional observational studies employing the Bradford Hill criteria [96] when evaluating the results or randomization within a trial are warranted to determine causality.

Future research

The research in this field is currently sparse, and the evidence whether prenatal, birth and early life factors are predictors of sedentary behavior is weak. There is a further need to understand whether associations develop through physical/mechanical pathways, for example accumulating adipose tissue might constrain physical movement; or through metabolic pathways, for example early adaptations in fuel metabolism might influence the availability for fuel utilization for physical activity at later ages. This applies not only to the development within a child, but also the intergenerational associations of maternal pregnancy physiology with offspring sedentary behavior. To increase our knowledge whether factors early in life influence not only health outcomes but also health-related behaviors such as sedentary behaviors and physical activity, including accurate and valid assessment of these behaviors or analyzing existing data in high quality birth cohorts are warranted. The effect sizes for any association between prenatal, birth and early life predictors and sedentary behavior appear small, and studies must be adequately powered enough to detect these modest, but perhaps important associations.

Finally, although several potentially confounding factors have been included in existing studies, future studies may consider a wider range of both biological and sociodemographic confounders.

Conclusion

The results from this systematic review suggest that heritability and early childhood BMI may be potential predictors for sedentary behavior in young people. No evidence was found for a relationship between birth weight and gestational age and later sedentary behavior. There is insufficient evidence whether other prenatal, birth and early life physical factors act as predictors of later sedentary behavior in young people.

Additional files

Additional file 1: Search strategy (Pubmed). (DOCX 14 kb)

Additional file 2: Items included in the checklist for assessing the quality of the included studies. (DOC 22 kb)

Abbreviations

BMI, body mass index; PROSPERO, the international prospective register of systematic reviews.

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Availability of data and materials

The data supporting our findings can be found in Table 1.

Authors' contributions

Hildebrand, Ekelund and Øglund drafted and designed the study, in addition to extract the data. Wells revised it critically for important intellectual content. All authors were involved in interpretation of the data, have given final approval of the manuscript, and have agreed to be accountable for all aspects of the work.

Authors' information

None.

Competing interests

Hildebrand, Øglund, Wells and Ekelund declare that they have no competing interests.

Consent for publication

Not applicable.

Ethics approval and consent to participate

Not applicable.

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Appendix I

Approval letters from the Regional Committees for Medical and Health Research Ethics (REC) and Approval letters from NSD - Norwegian Centre for Research Data

Emne: Sv: Objektiv måling av fysisk aktivitet og stillesittende tid
Fra: post@helseforskning.etikkom.no
Dato: 24.10.2012 09:26
Til: maria_hildebrand@hotmail.com
Kopi:

Hei

Viser til fremleggingsvurdering mottatt 08.10.2012 for prosjektet "Objektiv måling av fysisk aktivitet og stillesittende tid".

Henvendelsen er vurdert av komiteens leder, Stein A. Evensen.

Formålet med prosjektet er å sammenligne registreringer fra ActiGraph GT3X+ og GeneActiv med energiforbruk under standardiserte aktiviteter blant barn og voksne. Er det en forskjell i registrert akselerasjon mellom de ulike målerne og plassering? Videre ønsker man å undersøke i hvilken grad de to målerne festet rundt håndleddet klarer å registrere stillesittende tid blant barn og voksne under free-living, sammenlignet med en allerede validert inclinometer (ActivPAL).

Prosjektet faller utenfor helseforskningsloven som forutsetter at formålet med prosjektet er å fremskaffe ny kunnskap om sykdom og helse. Prosjektet er ikke fremleggingspliktig for REK.

REK antar for øvrig at prosjektet kommer inn under de interne regler som gjelder ved forskningsansvarlig virksomhet. Du bør derfor ta kontakt med forskerstøtteavdeling eller personvernombud for å avklare hvilke retningslinjer som er gjeldende.

Med vennlig hilsen

Gjøril Bergva

Komitésekretær
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Vår dato: 29.10.2012 Vår ref:31925 / 3 / SSA Deres dato: Deres ref:

TILBAKEMELDING PÅ MELDING OM BEHANDLING AV PERSONOPPLYSNINGER

Vi viser til melding om behandling av personopplysninger, mottatt 25.10.2012. All nødvendig informasjon om prosjektet forelå i sin helhet 26.10.2012. Meldingen gjelder prosjektet:

31925	*Objektiv måling av fysisk aktivitet og stillesittende tid*
Behandlingsansvarlig	*Norges idrettshøgskole, ved institusjonens øverste leder*
Daglig ansvarlig	*Maria Hildebrand*

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 og helseregisterloven med forskrifter. Behandlingen av personopplysninger kan settes i gang.

Det gjøres oppmerksom på at det skal gis ny melding dersom behandlingen endres i forhold til de opplysninger som ligger til grunn for personvernombudets vurdering. Endringsmeldinger gis via et eget skjema, http://www.nsd.uib.no/personvern/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://pvo.nsd.no/prosjekt.

Personvernombudet vil ved prosjektets avslutning, 01.12.2013, rette en henvendelse angående status for behandlingen av personopplysninger.

Vennlig hilsen

Vigdis Kvl
Vigdis Namtvedt Kvalheim

Sondre S. Arnesen

Kontaktperson: Sondre S. Arnesen tlf: 55 58 25 83
Vedlegg: Prosjektvurdering

Avdelingskontorer / *District Offices*:
OSLO: NSD. Universitetet i Oslo, Postboks 1055 Blindern, 0316 Oslo. Tel: +47-22 85 52 11. nsd@uio.no
TRONDHEIM: NSD. Norges teknisk-naturvitenskapelige universitet, 7491 Trondheim. Tel: +47-73 59 19 07. kyrre.svarva@svt.ntnu.no
TROMSØ: NSD. SVF, Universitetet i Tromsø, 9037 Tromsø. Tel: +47-77 64 43 36. nsdmaa@sv.uit.no

Appendix II

Informed consent forms

Forespørsel om deltakelse i forskningsprosjekt

Objektiv måling av fysisk aktivitet og stillesittende tid – sammenligning av ulike type aktivitetsmålere og plassering

Bakgrunn og hensikt
Det er nødvendig med gode og presise målemetoder for fysisk aktivitet for å kunne kartlegge hvor aktiv befolkningen er. En aktivitetsmåler er på størrelsen av en fyrstikkeske og måler fysisk aktivitet gjennom å registrere kroppens bevegelse. Det finnes i dag flere typer av aktivitetsmåler, men det er imidlertid usikkert om disse målerne registrerer fysisk aktivitet likt. Formålet med studien er å sammenligne to ulike typer aktivitetsmålere, samt to forskjellige plasseringer av målerne (hofte versus håndledd).

For at vi skal kunne gjennomføre denne studien ønsker vi deltakere i aldrene 7-10, samt 16-65 år og det er derfor vi spør om dette er aktuelt for deg.

Seksjon for idrettsmedisinske fag (SIM) ved Norges idrettshøgskole (NIH) er ansvarlig for prosjektet.

Hva innebærer studien?
Studien innebærer at du må komme til NIH for å gjennomføre noen hverdagslige aktiviteter, for eks. ligge, sitte fremfor PC og gange på tredemølle. Under aktivitetene skal du bære aktivitetsmålere, i tillegg til at ditt oksygenforbruk blir målt. Dette vil ta ca. 2 timer.

Etter dette ønsker vi at du skal fortsette bære målerne til neste dag (ca. 24. timer), med unntak av når du skal dusje eller sove. Dagen etter må du komme tilbake til NIH for å ta av målerne. At du bærer målerne vil ikke påvirke din hverdag, og vi ønsker at du skal leve som «vanlig» og gjøre ting som du ellers skulle gjort denne dagen.

Kriterier for deltakelse
Du må være frisk, ikke ha kontraindikasjoner til fysisk aktivitet, muskel-skjelettskade eller sykdom som påvirker ditt energiforbruk, for eksempel diabetes.

Mulige fordeler og ulemper
Testingen innebærer minimal risiko for skade og inneholder ikke nærgående undersøkelser. Hvis skade skulle inntreffe under testing er du forsikret gjennom NIH. Du vil ikke bli veldig sliten under testing, da de fleste aktiviteter foregår i lave intensitetssoner.

Hva skjer med informasjonen om deg?
Det er frivillig å delta i studien. Om du nå sier ja til å delta, kan du senere, uten å oppgi noen grunn, trekke tilbake ditt samtykke. Informasjonen som registreres om deg skal kun brukes slik som beskrevet i hensikten med studien. Alle opplysningene vil bli behandlet uten navn eller andre direkte gjenkjennende opplysninger. En kode knytter deg til dine opplysninger gjennom en navneliste. Det er kun autorisert personell knyttet til prosjektet som har adgang til navnelisten.

Ved prosjektslutt 01.12.2013 vil data anonymiseres og kan ikke knytes til deg personlig. Anonymisert data vil av hensyn til etterprøvbarhet og kontroll lagres i 10 år etter at prosjektet er avsluttet.

Eventuell kompensasjon til og dekning av utgifter for deltakere
Kostnad for transport til og fra NIH dekkes av studien.

Ytterligere informasjon om dine rettigheter finnes i Kapittel A. Ved ytterligere spørsmål, kontakt prosjektleder Maria Hildebrand tlf. 470 70 277 eller e-post maria.hildebrand@nih.no

Kapittel A: Informasjon om dine rettigheter

Personvern
Opplysninger som registreres om deg er:
- Alder
- Kjønn
- Dominant hånd
- Høyde
- Vekt
- Oksygenforbruk
- Aktivitetsregistreringer fra aktivitetsmålerne

Rett til innsyn og sletting av opplysninger om deg og sletting av prøver
Hvis du sier ja til å delta i studien, har du rett til å få innsyn i hvilke opplysninger som er registrert om deg. Du har videre rett til å få korrigert eventuelle feil i de opplysningene vi har registrert. Dersom du trekker deg fra studien, kan du kreve å få slettet innsamlede prøver og opplysninger, med mindre opplysningene allerede er inngått i analyser eller er brukt i vitenskapelige publikasjoner.

Økonomi
Studien er finansiert av forskningsmidler fra SIM, NIH. Det finnes ikke noen interessekonflikter.

Samtykke
Som helselovgivningen tilsier vil skriftlig samtykke fra personer på 16 år og oppover innhentes fra den enkelte. Hvis foresatte til ungdommer mellom 16-18 år ikke ønsker at deres barn skal delta i studien må de ta kontakt med prosjektleder.

Informasjon om utfallet av studien
Resultatene fra dette prosjektet vil bli presentert i en doktorgradsavhandling, samt publisert som minimum en artikkel i internasjonale tidsskrift og presentert ved nasjonale og internasjonale konferanser.

Skjema for samtykke til deltakelse i forskningsprosjekt
- Voksne over 16 år

Prosjekttittel Objektiv måling av fysisk aktivitet og stillesittende tid – sammenligning av ulike type aktivitetsmålere og plassering	Prosjektnummer
Prosjektleders navn Maria Hildebrand	Seksjon Seksjon for idrettsmedisinske fag

Det er frivillig å delta i studien. Dersom du ønsker å delta, undertegner du denne samtykkeerklæringen. Om du nå sier ja til å delta, kan du senere når som helst og uten å oppgi noen grunn, trekke tilbake ditt samtykke uten at det påvirker din øvrige behandling. Dersom du senere ønsker å trekke deg eller har spørsmål til studien, kan du kontakte prosjektleder.

Jeg er villig til å delta i forskningsprosjektet: Objektiv måling av fysisk aktivitet og stillesittende tid – sammenligning av ulike type aktivitetsmålere og plassering

Navn med blokkbokstaver	Fødselsdato
Dato	Underskrift

Fylles ut av representant for forskningsprosjektet

Jeg bekrefter å ha gitt informasjon om forskningsprosjektet: Objektiv måling av fysisk aktivitet og stillesittende tid – sammenligning av ulike type aktivitetsmålere og plassering

Dato	Underskrift	Brukerkode (4-tegnskode)

Eventuelle kommentarer:

Skjema for samtykke til deltakelse i forskningsprosjekt
- Barn under 16 år

Prosjekttittel	Prosjektnummer

Objektiv måling av fysisk aktivitet og stillesittende tid – sammenligning av ulike type aktivitetsmålere og plassering	
Prosjektleders navn Maria Hildebrand	Seksjon Seksjon for idrettsmedisinske fag

Det er frivillig å delta i studien. Dersom du på vegne av barnet sier ja til å delta, undertegner du denne samtykkeerklæringen. Om du nå sier ja til å delta, kan du senere når som helst og uten å oppgi noen grunn, trekke tilbake ditt samtykke uten at det påvirker barnets øvrige behandling. Dersom du eller barnet senere ønsker å trekke tilbake samtykket eller har spørsmål til studien, kan du kontakte prosjektleder.

Jeg sier på vegne av barnet ja til å delta i forskningsprosjektet: Objektiv måling av fysisk aktivitet og stillesittende tid – sammenligning av ulike type aktivitetsmålere og plassering

Barnets navn med blokkbokstaver	Barnets fødselsdato

Dato	Foresattes underskrift	Rolle (mor/far/verge)

Fylles ut av representant for forskningsprosjektet

Jeg bekrefter å ha gitt informasjon om forskningsprosjektet: Objektiv måling av fysisk aktivitet og stillesittende tid – sammenligning av ulike type aktivitetsmålere og plassering

Dato	Underskrift	Brukerkode (4-tegnskode)

Eventuelle kommentarer: