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Physical activity, sedentary time and adiposity in preschool children (Swiss Preschoolers' Health Study - SPLASHY)

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Physical activity, sedentary time and adiposity in preschool children (Swiss Preschoolers' Health Study - SPLASHY)

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Prof. Joan-Carles Suris

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ABSTRACT (ENGLISH)

The prevalence of obesity in preschool children has increased dramatically in the last 30 years. At the same time, children's physical activity levels have decreased and sedentary behaviours have increased. These trends are of great concern for public health due to their immediate and long-term consequences for the health of affected individuals. The preschool years (age 3-5 years) are regarded as critical for the establishment of a healthy lifestyle and a healthy weight. Yet, little is known about this young population. The thesis at hand provided a better understanding of the relationship of physical activity and sedentary behaviour with adiposity and the influence of the childcare environment on these factors in preschool children.

This research is based on the Swiss Preschoolers' Health Study (SPLASHY), a multi-site prospective cohort study aimed at understanding the influence of stress and physical activity on preschool children's psychological and physiological health. This thesis assessed and analysed cross-sectional and longitudinal measures of physical activity, sedentary behaviour and adiposity. Furthermore, it evaluated the influence of the child-care environment on physical activity, sedentary behaviour and adiposity.

Cross-sectional results identified a number of relevant factors: more frequent child-initiated interactions with other children during childcare, mixing different ages within a childcare group, the presence of a written physical activity convention, and/or a larger childcare surface. These were related to children's physical activity and sedentary behaviour during childcare days and mostly also to overall physical activity on both home and childcare days. Parental involvement in childcare physical activity projects correlated with reduced body fat. In addition, cross-sectional analyses showed that physical activity was positively associated with BMI and waist circumference in both the total population and in the normal weight group. Vigorous physical activity was negatively associated with body fat in the overweight and obese group, but not in the normal weight group. Longitudinal results showed that higher levels of total physical activity and moderate-to-vigorous physical activity predicted lower adiposity 1 year later. Sedentary behaviour did not predict adiposity 1 year later. Furthermore, adiposity did not predict physical activity nor sedentary behaviour.

These findings contribute to the current understanding of the relationship of physical activity behaviours with adiposity and confirm the benefits of being active from early childhood. We have identified particular childcare correlates of physical activity, sedentary behaviour, and adiposity that can be valuable targets for change in future interventions. Furthermore, encouraging children to engage in physical activity of at least moderate intensity may be more important to public health than reducing sedentary behaviour for preventing obesity in healthy preschool children.

RESUME (FRENCH)

La prévalence de l’obésité chez les enfants a augmenté considérablement au cours des trente dernières années. Parallèlement, le niveau d’activité physique (AP) des enfants a diminué et les comportements sédentaires ont augmenté. Ces tendances sont très préoccupantes pour la santé publique au vu de leurs conséquences immédiates et à long terme sur la santé des individus concernés. La période d’âge préscolaire (3 à 5 ans) est considérée cruciale pour la constitution d’habitudes de vie saines et d’un poids corporel sain. Pourtant, très peu de données existent sur cette jeune population. Cette thèse apporte une meilleure compréhension de la relation entre l’AP, la sédentarité et l’adiposité et l’influence de l’environnement de la crèche sur ces facteurs chez les enfants d’âge préscolaire.

Cette recherche fait partie d’une étude de cohorte prospective, Swiss Preschoolers’ Health Study (SPLASHY). C’est une enquête nationale sur la santé des enfants préscolaires en Suisse, qui a pour objectif de comprendre comment le stress et l’AP influencent la santé physique et psychologique des enfants de 3 à 5 ans. Cette thèse a évalué et analysé de manière transversale et longitudinale le lien entre l’AP, la sédentarité et l’adiposité. Aussi, elle a examiné l’influence de l’environnement de la crèche sur l’AP, la sédentarité et l’adiposité.

Les résultats transversaux ont identifié plusieurs facteurs importants : activités en interaction avec les autres enfants plus fréquemment initiées par l’enfant à la crèche, enfants d’âge différent dans le même groupe, présence d’une charte pour la promotion de l’AP et/ou plus grande taille de la crèche. Ces facteurs étaient associés à l’AP et à la sédentarité des enfants durant les jours passés à la crèche et aussi généralement à l’AP globale durant les jours de crèche et à la maison. La participation des parents aux projets d’AP de la crèche était corrélée à une diminution de la graisse corporelle. Aussi, les résultats transversaux ont montré que l’AP était positivement associée à l’indice de masse corporelle et au tour de taille chez tout l’échantillon et chez les enfants de poids normal. L’AP vigoureuse était associée négativement avec la graisse corporelle chez les enfants en surpoids et obèses, mais pas chez les enfants de poids normal. Les résultats longitudinaux ont montré que des niveaux plus élevés d’AP totale et d’AP modérée-à-vigoureuse prédisent une adiposité inférieure un an plus tard. L’activité sédentaire ne prédit pas l’adiposité un an plus tard. De plus, l’adiposité ne prédit pas les niveaux d’AP et de sédentarité.

Ces résultats contribuent à la compréhension actuelle de la relation entre l’AP, la sédentarité et l’adiposité. Ils confirment les effets bénéfiques de l’AP dès la petite enfance. Nous avons identifié des corrélations lors des périodes passées à la crèche entre AP, sédentarité et adiposité, qui pourront être intégrées dans de futures études d’interventions. Egalement, encourager les enfants à participer à des AP au moins d’intensité modérée peut s’avérer plus important pour la santé publique que réduire les comportements sédentaires pour prévenir l’obésité chez les enfants préscolaires sains.

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GLOSSARY AND DEFINITIONS

PHYSICAL ACTIVITY	Bodily movement produced by the skeletal muscle in substantial increase over the resting energy expenditure.
PHYSICAL INACTIVITY	An insufficient physical activity level to meet present physical activity recommendations.
SEDENTARY BEHAVIOUR	Any waking behaviour characterized by an energy expenditure ≤1.5 METs while in a sitting, reclining, or lying posture.
INFANTS	Aged less than 1 year.
TODDLERS	Aged 1-2 years.
PRESCHOOLERS	Aged 3-5 years.
CHILDREN	Aged 6-11 years.
YOUTHS	Aged 12-17 years.
YOUNG CHILDREN	Children less than 5 years of age.

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LIST OF ABBREVIATIONS

ADP: air displacement plethysmography

BF: body fat

BIA: bio impedance

BMI: body mass index

CC: childcare

CT: computed tomography

DXA: dual energy x-ray absorptiometry

EPAO: Environment and Policy Assessment and Observation

EPAO-SR: Environment and Policy Assessment and Observation – Self-Administered

ICAD: International Children's Accelerometry Database

IOTF: International Obesity Task Force

KG: kilogram

M: metre

METs: metabolic equivalents

MRI: magnetic resonance imaging

MVPA: moderate-to-vigorous physical activity

NAP SACC: Nutrition and Physical Activity Self-Assessment for Child Care

NW: normal weight

OW: overweight

OB: obesity

PA: physical activity

SB: sedentary behaviour

SBRN: Sedentary Behaviour Research Network

SD: standard deviation

SES: socio-economic status

SF: skinfold thickness

SPLASHY: Swiss Preschoolers' Health Study

ST: sedentary time

TV: television

US: United States

USA: United States of America

UTS: ultrasound

VPA: vigorous physical activity

WC: waist circumference

WHO: World Health Organisation

WHtR: waist-to-height ratio

1. GENERAL INTRODUCTION

1.1. Childhood obesity

Obesity is one of the greatest public health challenges of the 21st century. Global data suggest that overweight (OW) and obesity (OB) are reaching alarming proportions and pose urgent and serious challenges [1, 2]. In 2015, excess weight affected 2.2 billion individuals, or 30% of the global population [2]. The OB epidemic also affects children and adolescents. Nearly 124 million children and adolescents aged 5-19 years are considered obese [3]. The global prevalence of childhood OB has more than doubled since 1975, and the rate of increase is greater than that of adults (Figure 1).

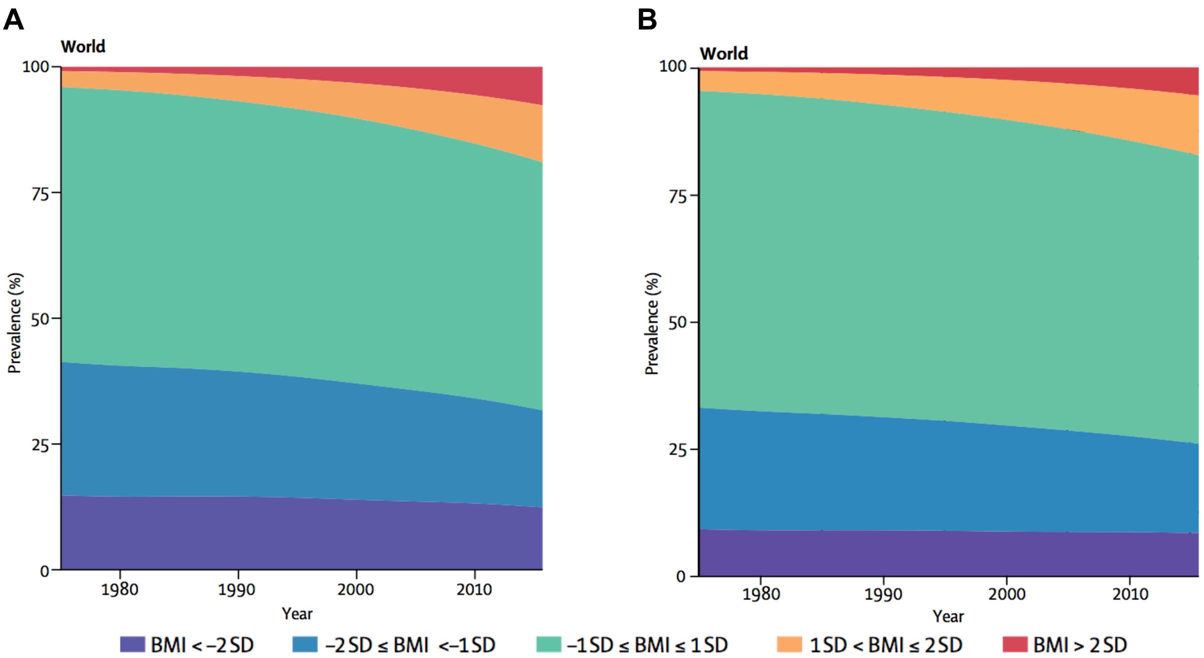

Figure 1. Trends in age-standardized prevalence of BMI categories in boys (panel A) and girls (panel B) children and adolescents aged 5-19 years. Obesity was defined as more than 2 SD above the median of the WHO growth reference [3].

For a more detailed global prevalence of OB and Body Mass Index (BMI) trends since 1975 based on the Non-Communicable Disease Risk Factor Collaboration, please refer to Appendices I and II [3].

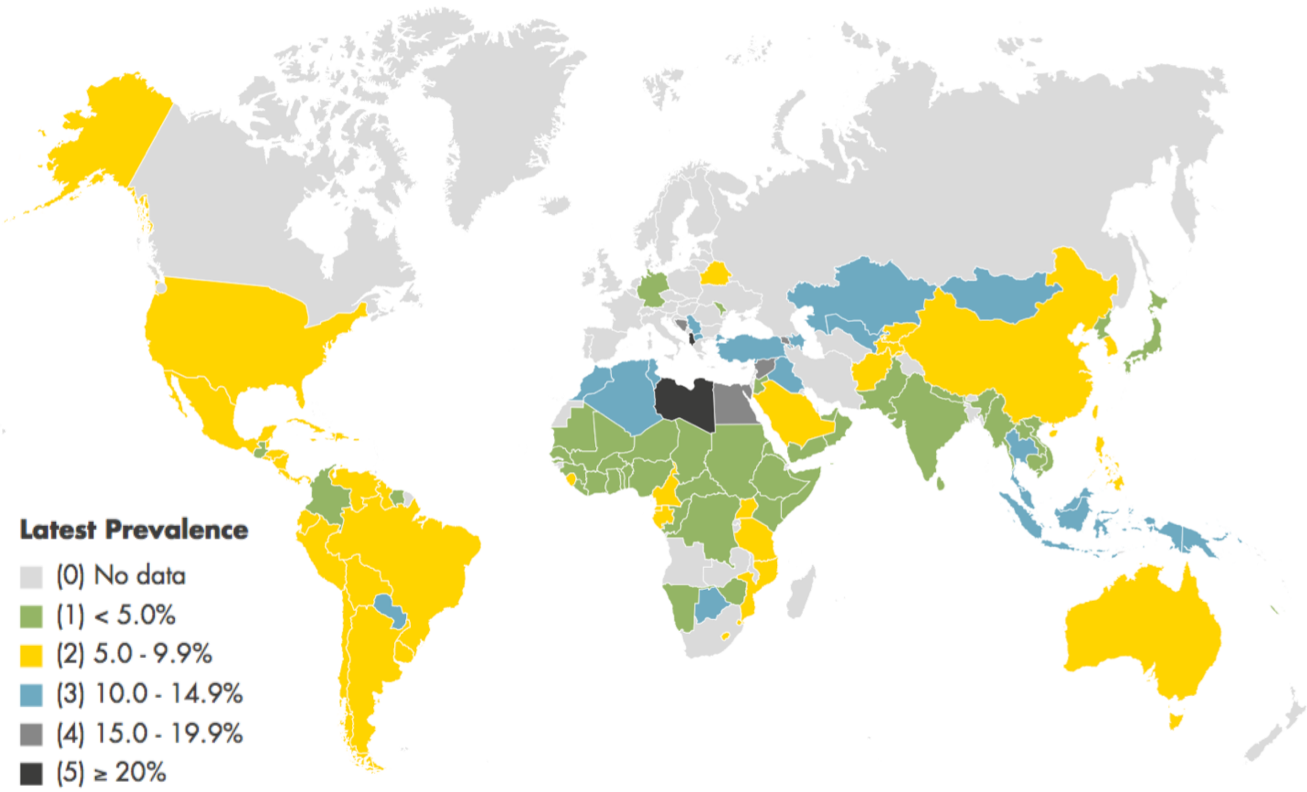

Figure 2. Prevalence of overweight worldwide in children under 5 years of age, 2014 (WHO).

In 2015, an estimated 42 million children under 5 years of age were affected by OW or OB, even in developing countries (Figure 2) [4].

In Europe, the latest estimated prevalence of OW excluding OB in children under 5 years of age is 12% based on the World Health Organisation (WHO) classification [4]. For children below the age 10, the prevalence of OW including OB is 28% based on the WHO classification and 20% based on the International Obesity Task Force (IOTF) classification [5]. Switzerland is no exception to the worldwide trend in high prevalence of childhood OW and OB. The proportion of OW including OB in children aged 6 years is 12% and in children and adolescent (6-15 years-old) is 17% based on the IOTF classification [6]. Interestingly, the prevalence of excess weight in children and adolescents has stabilized in Switzerland in recent years [6, 7], and there was even a slight decrease in the prevalence of OW and OB in preschool children from 2005 to 2016 [6]. Nonetheless, the prevalence of OW and OB remains high in this population.

Obesity starts very young and has a tendency to persist. According to the Early Childhood Longitudinal Study, the incidence of OB between the ages of 5 and 14 years was four times as high among children who had been OW at the age of 5 years as among children who had a normal weight (NW) at that age [8]. Consequently, by the age of 14, 45% of children who became obese were already OW at the age of 5 years (Figure 3). As the authors suggested, it is clear that a component of the development of OB is already established by the age of 5 years [8]. Therefore, establishing a healthy weight in preschool years is paramount. Understanding the factors associated with the development of OW and OB during the first years of life is of great importance. Future longitudinal research is needed, for example, to understand the contribution of physical activity (PA) and sedentary behaviour (SB) to the development of childhood OB during the preschool years (3-5 years of age).

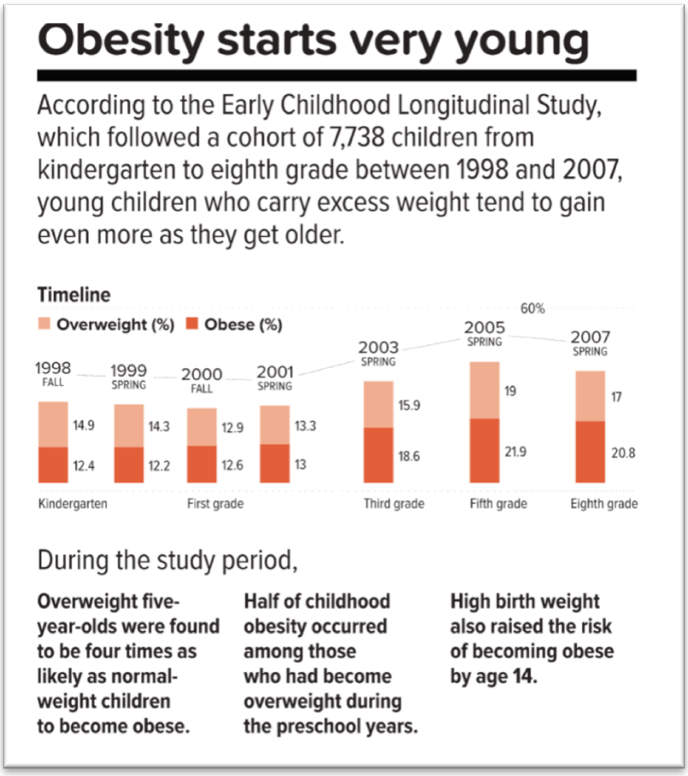

Figure 3. Obesity trend in early years in US population [8].

1.1.1. Overweight and obesity definitions

The WHO defines OB as a condition of abnormal or excessive body fat (BF) accumulation, which may increase the risk of morbidity or mortality [9]. The term adiposity is often used interchangeably with OB as it is used to denote excess BF. Body mass index is a simple weight-for-height index (kg/m^2) used to classify OW and OB in adults. For adults, the WHO defines OW as a BMI ≥25 and OB as a BMI ≥30, although values are lower in Asian populations [9]. In children, age and sex need to be considered when defining OW and OB. The WHO defines OW as ≥85th percentile and OB >97th percentile for children aged 0-19 years old [10]. More details of other definitions and tools to assess adiposity are discussed in section 1.2 (*Adiposity assessment*).

1.1.2. Health consequences

Childhood OB poses serious health consequences. Indeed, elevated adipose levels (adiposity) are associated with higher chances of OB, premature death, and disability in adulthood [11]. A detailed description of the many health consequences of childhood OB would be beyond the scope of the present thesis. In summary, the short-term consequences of paediatric OB include psychological or psychiatric problems, low self-esteem, behavioural problems, asthma, metabolic syndrome, type 1 diabetes, orthopaedic problems, and chronic inflammation. The long-term consequences of paediatric OB include persistence of OB from childhood, social and economic effects, gallbladder diseases, sleep apnoea, osteoarthritis, cancer, cardiovascular diseases, and risk of premature death in adulthood [9, 11].

1.1.3. Aetiology of childhood obesity

Childhood OB is multifactorial and includes genetic, epigenetic, physiological, cultural, environmental, individual, and socio-economic factors. It is the interaction between these different factors that contributes to the development of unhealthy weight gain and OB throughout the life course [9]. However, the fundamental cause of the present global epidemic is most likely an imbalance between energy intake and energy expenditure. Indeed, the socio-ecological model, as described by Davidson et al., indicates that dietary factors, PA, and SB patterns strongly influence the energy balance equation and are considered to be the major modifiable behaviours acting on weight gain [12]. Dietary factors are complex and are beyond the scope of the present thesis. Conversely, PA is considered the most variable component of total energy expenditure. Physical activity refers to any bodily movement produced by the contraction of skeletal muscles that results in a substantial increase in caloric requirements over resting energy expenditure [9]. There is strong and consistent evidence that PA, especially higher intensity PA, in children and youths is favourably associated with adiposity, several cardiometabolic biomarkers (cholesterol, blood pressure, triglycerides, insulin resistance, fasting insulin, and fasting glucose), physical fitness, and bone health [13]. There is evidence that higher levels of PA in preschool children are associated with better measures of adiposity, bone and skeletal health, motor skill development, psychosocial health, cognitive development, and aspects of cardiometabolic health [14]. Furthermore, a systematic review of prospective studies found an inverse association between PA and OW [15]. In contrast, SB refers to any waking behaviour characterized by an energy expenditure $\leq$1.5 metabolic equivalent (METs) while in a sitting, reclining, or lying posture [16]. In children and youths, higher levels of SB are associated with adverse health effects such as adiposity, metabolic syndrome, cardiovascular disease, poor psychological health, poor academic achievement, and low fitness [17, 18]. In preschool children, increased TV viewing has been associated with unfavourable measures of adiposity, psychosocial health and motor skill development [15, 19]. However, more and higher quality prospective studies using objectively measured PA and SB are required to draw firm conclusions on the associations between PA behaviours and health indicators (i.e. adiposity) in preschool children [13, 15, 18, 19].

1.2. Adiposity assessment

Appropriate assessment of childhood adiposity is important in identifying children at risk. Indeed, several different measures are available, from indirect techniques including weight, height, BMI, waist circumference (WC), waist-to-height ratio (WHtR), bioelectrical impedance (BIA), and skinfold thickness (SF) to more direct and technical approaches including dual energy x-ray absorptiometry (DXA), air displacement plethysmography (ADP), magnetic resonance imaging (MRI), computed tomography (CT), and ultrasound (UTS) [20]. These direct techniques are considered highly accurate because of their direct quantification of body composition. Clinical techniques such as BMI, WC, WHtR, SF and BIA are widely used in research. Because of their simplicity, speed, low cost, and tolerance by children, they are more practicable for large epidemiological studies than more complex and expensive methods (i.e. DXA or CT) [20-22]. In the current thesis, we used the following measures of body composition: BMI, BMI z-score, WC, WHtR, and SF.

1.2.1. Body mass index

The BMI is a simple measure of weight-for-height and is a proxy of adiposity. However, it is not a measure of body composition [20]. Unlike adults, children BMI depends on age and sex. Since children experience growth, changing body composition, and natural fluctuations in adiposity, age-and-sex-adapted BMI percentiles or z-scores should be used to determine the BMI status of children under 18 years of age [20]. Indeed, BMI percentiles are generally useful in clinical settings; they are easy to understand and to use because they rank the position of an individual in a population. Conversely, BMI z-scores are based on the distribution of the reference population, and as standardized continuous measures, they are useful when comparing studies across age and sex [23].

Two main international BMI reference curves are available and enable individual assessment of weight status. First, in 2006 the WHO released new references for assessing growth of children from birth to 5 years of age. These references were constructed from samples composed of healthy breast-fed children from Brazil, Ghana, India, Norway, Oman, and the USA [10]. They were intended to present a standard of physiological growth rather than a descriptive reference. In 2007, the WHO developed references for school-aged children and adolescents aged 5-19 years old to provide a smooth transition from the WHO standard curves for under-fives to the reference curves for older children. However, the 2007 references curves are based on data from US surveys [24].

In 2000, the IOTF developed BMI percentiles based on six nationally representative data sets to define childhood OW and OB: Brazil, Great Britain, Hong Kong, the Netherlands, Singapore, and the USA [25]. These references are smooth age-and-sex-specific BMI percentiles constructed to match the values of 25 and 30 kg/m^2 at 18 years.

A review by Reilly et al. showed that the definition of OW and OB based on BMI for age with national reference data was superior to that using BMI with the IOTF approach [26]. However, many national reference data for BMI by age are not available, and the WHO or IOTF data are recommended as alternatives; these also have the advantage of being comparable between studies. Switzerland possesses national references [27]. Nevertheless, these national references pose serious limitations. First, these references are purely descriptive, and their primary purpose was originally to track individual growth and development. Secondly, the sample is not representative of the Swiss population: the sample size is too small (n=274), exclusively from middle-to-high income families, and mainly from one region, Zurich. Thirdly, these references are outdated for current use, since the children comprising the original sample were born between 1954 and 1956. Indeed, breastfeeding practices have changed since the 1950s, and today's children are heavier than 60 years ago. Finally, there was no harmonization in national reference data, because the German and French speaking parts of Switzerland used different data sets [28]. For these reasons, the Growth Curves working group of the University of Zurich proposed using the 2006/2007 WHO references curves [28]. Today, Switzerland has adopted the WHO references to define OW and OB in children and adolescents, but for clinical purposes it has decided to use slightly different cut-offs (90th instead of 85th percentile to define OW) [28, 29].

The BMI definitions are very helpful when comparing different population groups or monitoring a population over time [30]. However, BMI has been criticized regarding its validity as an indicator of adiposity among children [31-34]. Indeed, BMI as an indicator of adiposity varies substantially according to the degree of BF levels. Among relatively thin children (i.e. BMI for age <85th WHO percentile), differences in BMIs are largely due to differences in fat-free mass [31-33]. Therefore, comparisons of BMIs across groups that differ in age or when predicting adiposity should be interpreted with caution. BMI may also be affected by ethnic differences in body composition. Additionally, the WHO and IOTF reference curves are based on two distinct samples, consequently resulting in different prevalence rates. For these reasons, the following recommendations have been established [30] :

- Results must be interpreted cautiously.
- Use both IOTF and WHO definitions to assess the prevalence of childhood OW and OB.
- Definitions should be stated explicitly with exact terminology (i.e. OW including or not including OB).

- Other measurements of adiposity according to standardized procedures should be performed in conjunction.

1.2.2. Skinfold thickness

Skinfold thickness can be measured at many sites, but the most common are biceps, triceps, subscapular, suprailiac, and thigh. Skinfold thickness measurement is relatively inexpensive, is widely used to calculate adiposity in children, and has been found to accurately reflect adiposity in children [20]. However, issues have been raised regarding reliability and accuracy, and considerable expertise is required for accurate measurement. Furthermore, although standardized equations exist to calculate BF in children, their validity has not yet been established [20]. Reilly et al. cross-validated five commonly used prediction equations using hydrodensitometry and found these equations to be biased and associated with large random and systematic errors [35]. Therefore, SF should be used as a stand-alone measure rather than incorporating it in prediction equations [35]. Furthermore, SF was shown to be highly correlated with total fat mass as measured by DXA in school-aged children (n=1100), and it was found to be an adequate surrogate measure of relative adiposity in children when DXA is not practical [36].

1.2.3. Waist circumference

Waist circumference is a very useful and simple measure of central adiposity [20] that has been associated with numerous cardiovascular and metabolic risk factors [37]. Taylor et al. found that WC performs better as an indicator of high trunk fat mass in preschool children than DXA [38]. Furthermore, a recent review showed evidence supporting the use of WC in the measurement of BF in 7-10 year-old children when more accurate techniques are not feasible [22]. However, there is no consensus or international WC reference data in children, and measurement procedure has not been standardized [20]. Even though WC has been shown to be well correlated with intra-abdominal fat in preschool children, over- and underestimation may occur for very tall or very short individuals with similar WC [39]. To overcome these limitations, the WHtR has been recommended for more accurate estimation of central fat [40, 41]. Finally, the affordability, harmlessness, and ease of measurement of both WC and WHtR make them suitable for large epidemiological studies in children.

In summary, the core clinical measurements of weight, height, BMI, BMI z-score, WC, and WHtR are sufficient to detect adiposity in children, while more technical tools provide further insights. Skinfold thickness should be included as an additional measurement of adiposity since it is the most cost-effective method for BF measurement, even if it requires a high standard of technical training [20].

1.3. Physical activity and sedentary behaviour in young children

Preschoolers' PA patterns under natural conditions are characterized by short bursts of intense PA interspersed with brief rest periods [42]. Indeed, activities mainly take the form of basic movements and fundamental movement skills. Participation in modified sports such as football, basketball, and tennis may begin in later preschool years (around the ages of 4-5) [43]. Children participate in PA to have fun, to make friends, and to learn new things. Furthermore, regular participation in a variety of PA is essential for optimal growth and development [44]. Recent evidence shows that PA can have beneficial effects on body composition, cardio-metabolic markers, aerobic fitness, muscular strength, bone health, movement skills, academic performance, cognition, and well-being [13]. Limiting SB is also important for healthy development. Indeed, higher levels of SB are associated with unfavourable body composition, higher metabolic risk scores, unfavourable psychosocial behaviour, lower fitness, and lower self-esteem [18]. Physical activity behaviours and SB are formed during the early years of life and track into adulthood [45]. Furthermore, developing fundamental movement skills during the early years is important as these serve as the building blocks for PA throughout the life course [46]. Thus, it is important to educate young children about the health and well-being benefits of PA and encourage PA participation in the early years.

The WHO commission on ending childhood OB recommends the early promotion of PA and the reduction of SB to reverse the rising trend of children under 5 years developing OW and OB [4]. Consequently, it is essential that researchers and practitioners measure PA and SB accurately and reliably. Currently, a wide variety of measures are used to track PA behaviours in children. The most common methods include self-reports such as questionnaires, proxy reports from parents and teachers, and objective methods such as heart rate, pedometer, direct observation, doubly-labelled water, and accelerometer [47]. The use of accelerometers to objectively measure PA and SB/ sedentary time (ST) is now common and well established in research on children. Also, accelerometers can quantify PA intensity.

1.3.1. Physical activity assessment

Accelerometry is becoming more common and provides a practical, reliable, and valid means of quantifying the amount and intensity of PA and ST in children [48]. It is also useful in examining trends in activity patterns and associations between activity and health outcomes. Accelerometers are devices that measure acceleration of body movements and produce outputs in counts per unit of time (epoch). These counts have no biological meaning and must be converted to amount and intensity of PA and ST (i.e. time spent in moderate-to-vigorous PA: MVPA) [48]. Epoch lengths used in such research range from one second to one minute [49]. Because of the PA patterns of young children, it is believed that shorter epochs (15-s) are more appropriate in children. However, the empirical evidence is limited and does not support the notion that short epochs are essential [48, 50]. The accelerometer mostly used by researchers is the Actigraph (Pensacola, Florida). All Actigraph devices capture movement in the longitudinal or vertical axis (up and down movement) and are referred to as uni-axial accelerometers. Moreover, some accelerometers are bi-axial and capture movement in an additional anteroposterior or horizontal axis (forward and backward movement). The latest Actigraph tri-axial model (GT3X) detects movements in three axes: vertical, horizontal, and mediolateral (side to side) [50]. From a behavioural perspective, measuring PA in three axes has advantages over one axis, especially when children's omnidirectional PA patterns are considered, but more evidence is needed to draw firm conclusions [43]. Accelerometry provides an objective measure of PA and ST, thus avoiding the biases that can be introduced by self-report or proxy reports. It allows researchers and practitioners to measure PA intensities and patterns during waking hours over several days for a large number of subjects

[51]. A disadvantage of accelerometers is that they do not provide information on activity type or context. Furthermore, accelerometers are limited in their ability to measure non-weight-bearing activities, such as cycling or upper limb movements, and they are not waterproof and thus cannot be used to measure swimming or water activities [51].

Measuring PA behaviour in children is challenging because of the sporadic and intermittent nature of their movement behaviour [43]. Additionally, the rapid development of the field has confronted practitioners and researchers with a data collection and processing criteria dilemma [50]. For example, epoch length (long epoch: 60-s or short epoch: 15-s) and axis vector (uniaxial or triaxial) selection have been shown to affect PA and SB outcomes (i.e. prevalence of MVPA) [52]. Therefore, methodological considerations should be well considered when using accelerometers to assess PA and ST in young children. Practical data collection and processing criteria when using the Actigraph GT3X with preschool children are presented in Table 1. These data reduction criteria are based on a recent review [50].

Table 1. Summary of practical considerations for physical activity and sedentary time measurement using accelerometers in preschool children.

Data reduction criteria	Evidence-guided protocol
Device placement	• Use hip or wrist for placement as they offer similar estimates of PA.
Sampling frequency[a]	• Use the highest frequency possible 90-100 Hz (or multiple of 30Hz).
Valid day[b]	• Insufficient evidence for wear time criteria for valid day. More is better, but test for best compromise between sample size and reliability of measures.
Valid week	• A minimum of 4 days of valid data is recommended.
Filter[c]	• No data available in preschoolers (normal or low-frequency). • The filter should be the same as that used in the validation study from which cut-points and algorithm have been taken.
Epoch length[d]	• Shorter epochs are suitable (1-15 seconds). • Insufficient evidence on the influence of epoch length on accelerometer output. • Epoch length should be the same as that used in the validation study from which cut-points and algorithm have been taken.

Non-wear time	• Insufficient evidence for definition. • empirical evidence suggests defining 20 consecutive minutes of “0” counts or more as “non-wear time”.
Registration period protocol	• 24hr is recommended instead of waking hours: it provides more valid data and higher wear-time compliance.
PA and SB cut-points	• It is recommended to follow the same data collection and processing criteria that used in the validation study from which cut-points and algorithm have been taken. • Use Costa et al. [53] for early preschoolers (2-3-years old). • Use Jimmy et al. [54] for older preschoolers (4-6-years old).
PAEE algorithms	• Use Butte et al.’s [55] algorithm: it is the only one validated in free-living conditions against doubly labelled water.

PA: physical activity; Hz: hertz; SB: sedentary behaviour; PAEE: physical activity energy expenditure.
[a]*Sampling frequency* refers to the rate of data acquisition.
[b]*Valid day* refers to a minimum number of recording hours per day.
[c]*Filter* is the process by which the acceleration data is cleaned (noise elimination).
[d]*Epoch length* refers to the time sampling interval or the time period over which accelerometer counts are averaged [56].

Table 2 summarizes the classification of different PA intensities by their activity energy expenditures.

Table 2. Classification of physical activity intensities and activity energy expenditure.

Physical activity intensities	Activity Energy Expenditure
Light PA	1.5-3 METs
Moderate PA	3-6 METs
Vigorous PA	≥6 METs
Moderate-to-vigorous PA	≥3 METs
Sedentary behaviour	≤1.5 METs

Accepted criteria to define PA intensity in the studies validating cut-points against indirect calorimetry [50, 57]. PA: physical activity; METs: metabolic equivalents; kcal: kilocalorie; kg: kilogram; min: minute.

1.3.2. Sedentary behaviour assessment

Research on SB has grown rapidly in recent years. Indeed, SB and ST are considered separate and distinct from a lack of PA (i.e. not meeting specified PA guidelines), and evidence indicates that sedentary lifestyles also occur in the early years [19]. Consequently, interest has increased in the health consequences of excessive SB during early development years.

Indeed, SB and ST have emerged as risk factors for adiposity and other adverse health indicators independently of PA levels [18, 58, 59]. However, substantial confusion exists regarding clear, common, and accepted terminology and definitions for SB. For this reason, the Sedentary Behavior Research Network (SBRN) Terminology Consensus Project recently presented standardized definitions and encouraged researchers to embrace, use, and promote them (Figure 4) [16]. Additionally, different types of SB exist, which makes it difficult to measure. Sedentary behaviour can be measured objectively by accelerometry to capture time spent in SB, including bouts and/or interruptions or breaks. The main types of SB measured subjectively (via parental or self-report questionnaire, diary, or interview) are screen time, TV viewing, computer use, video game use, and non-screen time (i.e. reading, homework, playing a musical instrument) [16, 18].

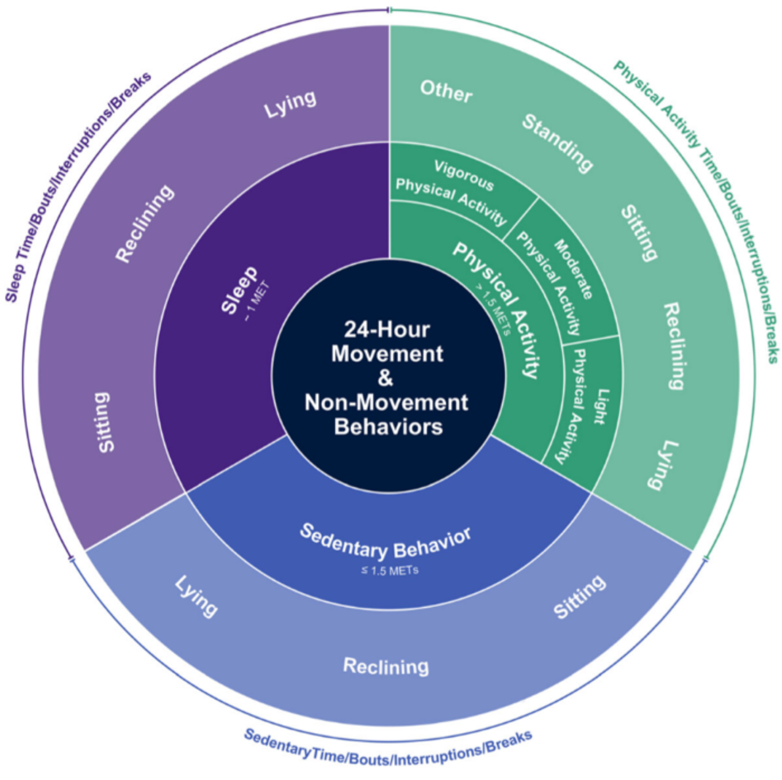

Figure 4. Final conceptual model of movement-based terminology arranged around a 24-hr period. The figure organizes the movements that take place throughout the day into two components: The inner ring represents the main behaviour categories using energy expenditure. The outer ring provides general categories of posture [16]. Source: SBRN Terminology Consensus Project.

1.3.3. Physical activity and sedentary behaviour recommendations

It is clear that PA is important for physical and mental health (see section 1.3) [13, 60]. For this reason, the WHO *Global Recommendations on Physical Activity for Health* [61], and many other guidelines around the world (Australia [62], Canada [63], and the USA [64]), recommend that children and youths aged 5-17 should accumulate at least 60 min of MVPA daily. Also, within these 60 min, vigorous PA (VPA) should be incorporated at least three times per week [61]. Moreover, children and youths aged 5-17 should limit use of electronic media for entertainment to no more than two hours a day and break up long periods of sitting as often as possible [61-63]. These international PA guidelines for children and youths are based on the best available scientific evidence (systematic reviews, observational studies, interventions) and experts' and policy-makers' opinions. Moreover, these guidelines represent a minimum target for daily PA that provides minimal and optimal health benefits and prevention of noncommunicable diseases [61-65]. For preschoolers 3-5 years of age, the following international PA guidelines (Australia [66], Canada [67, 68], Switzerland [69], United Kingdom [70], and the USA [71]) recommend: 1) accumulating at least 180min of PA at any intensity spread throughout the day, 2) including a variety of activities in different environments, 3) including activities that develop movement skills, and 4) progressing toward at least 60 minutes of energetic play per day by 5 years of age (see Figure 5).

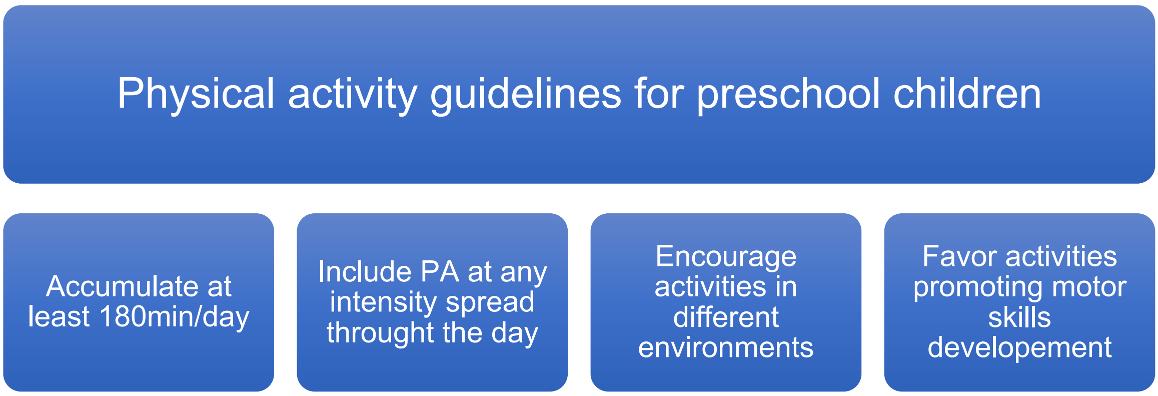

Figure 5. Physical activity guidelines for preschool children for healthy growth and development [68].

Moreover, Australia and Canada have also created guidelines for SB for preschool children. These SB guidelines recommend 1) minimizing the time spent sedentary during waking hours, 2) avoiding prolonged sitting, being restrained, or remaining inactive for more than 1hr at a time, 3) no screen time (TV, computer, electronic games) for children under 2 years of age, and 4) limiting screen time to under 1hr per day for children 2-4 years of age (see Figure 6) [67, 72, 73]. It is important to note that physical inactivity is not SB. Physical inactivity refers to an insufficient PA level to meet present PA recommendations [16]. These guidelines of PA and SB for preschoolers are based on the best available evidence and experts' opinions. Yet, the literature in this field is at an early stage of development and more evidence is needed to understand the frequency, intensity, duration, and type of activity associated with better health indicators and improvements in health indicators [14, 68].

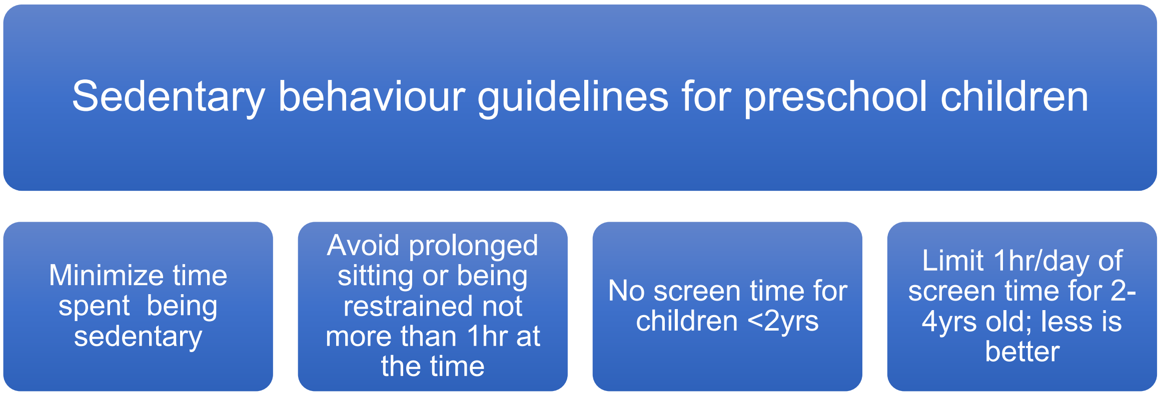

Figure 6. Sedentary behaviour guidelines for preschool children for healthy growth and development [72].

1.3.4. Prevalence of physical activity and sedentary behaviour

According to international research, preschool children engage in low levels of PA (i.e. MVPA) and very high levels of ST [13, 74-78]. Furthermore, one systematic review concluded that only 54% of children aged 2 to 6 years met the PA guidelines [76]. However, examining the prevalence of children meeting the new PA and SB guidelines is difficult due to differences in data reduction methodology and the limited data available about preschool children [79, 80]. For example, in a recent US cross-sectional study, approximately half of the preschool children met the PA guidelines [81]. In an Australian study, only 5% of preschool children met the PA guidelines [82]. In contrast, 74% of preschool children in a Portuguese study met the PA guidelines [83]. Standardizing the data reduction methodology would enable comparison between studies and provide a large database for analyses, thus increasing statistical power, and for these reasons the International Children's Accelerometry Database (ICAD) has been established [84]. Recently, a large study using the ICAD database showed that among 5-17year-olds (n=10 741), just 9% of boys and 2% of girls met the PA guidelines of achieving 60min of MVPA per day [85]. Another ICAD study showed that in a sample of children aged 4-17 years (mean age 11.7 years), at least 2/3 of participants exceed 2hrs/day of screen time.

The high prevalence of screen time was among boys, those who were OW or obese, and those with lower maternal education [86]. Nonetheless, other reasons may explain variability among studies, namely differences in accelerometer data reduction, variations in inclusion criteria, and sample differences. Clearly, standardization of methods is urgently required for research into PA and ST in preschool children. No, age-related cut-point values have been universally agreed, and guidance for interpreting accelerometry data in longitudinal research is limited [87]. Furthermore, data recently submitted from our own study confirm these discrepancies and discordances and challenge the validity of PA guidelines for preschoolers.

1.4. Correlates and determinants of physical activity and sedentary behaviour

Understanding factors that influence children's health behaviours is important in tackling childhood OB. Effecting positive behaviour change (i.e. higher PA / lower SB), first requires the identification of the correlates and determinants of change in young children [88]. Correlates refer to factors associated with activity in cross-sectional studies, and determinants refer to longitudinal predictors with a causal relationship [88]. The socio-ecological model of health behaviour is a framework commonly used for categorizing potential correlates and determinants of children's behaviour across five domains: demographic/biological, psychological/cognitive/emotional, behavioural, sociocultural, and physical environment [89, 90]. Such a framework enables researchers to understand the multiple and interacting determinants of health behaviour and ultimately develop comprehensive intervention approaches that target mechanisms of change at each level of influence [89].

A comprehensive systematic review by Sallis et al. [90] investigated the correlates of PA in children and youths. In summary, being a male, having an OW parent, having intentions and preferences for PA, previous PA, healthy diet, access to facilities and programmes, and time spent outdoors were all associated with greater PA. In contrast, greater perceived barriers were associated with less PA. See Table 3 for an overview of variables that are consistently associated with children's PA.

Table 3. Summary of correlates of physical activity in children and youths based on Sallis et al.'s review.

Demographic-Biological	Psychological-cognitive-emotional	Behavioural	Socio-cultural	Physical Environment
Sex (male) Parental OW status	PA preferences Intention to be active Perceived barriers	Previous PA Healthy diet	No variable	Program/facility access Time spent outdoors

PA: physical activity; OW: overweight.
Correlates were categorized by the socio-ecological model of health behaviour [90].

In preschool children, only a few consistent correlates of higher levels of PA have been reported; these included sex (male), parents' participation in child PA, parental PA, time spent outdoors, and gross motor skills (see Table 4) [91-93]., Evidence regarding SB is insufficient to draw conclusions about correlates [94].

Table 4. Summary of correlates of physical activity during the early years (age 0-6 years).

Demographic-Biological	Psychological-cognitive-emotional	Behavioural	Socio-cultural	Physical Environment
Sex (male) Gross motor skills	No variable	Parental involvement in child PA Parental PA	No variable	Time spent outdoors

PA: physical activity.
Correlates were categorized by the socio-ecological model of health behaviour [90].

Young children now spend increasingly large amounts of time in out-of-home care [95-97]. Consequently, the childcare (CC) environment is likely to exert a great influence on young children's health behaviours [98]. Two main valid and reliable assessment instruments exist to examine the nutrition and PA environment in the CC. The first is the Nutrition and Physical Activity Self-Assessment for Child Care (NAP SACC) questionnaire, which is based on a set of best-practice recommendations [99]. The second instrument is the Environment and Policy Assessment and Observation-Self-Report (EPAO-SR) [100], which is the self-administered version of the original researcher-administered Environment and Policy Assessment and Observation (EPAO) [101]. Both NAP SACC and EPAO-SR were developed to allow researchers and CC providers to evaluate the CC environment.

Differences in CC quality and health promotion in the CC setting can impact children's health. The CC environment has been shown to influence young children's PA behaviours, physical fitness, motor skills, and body weight [74, 75, 92, 98, 102-105]. However, research into the CC correlates of PA is recent; most of the evidence is from the US, and correlates/determinants differ greatly by country and by the CC context and setting [92]. For example, initial US studies found that more active opportunities, staff PA training and education, more portable play equipment, and larger playgrounds were correlates of PA [106-108]. In contrast, Australian studies found that less time spent indoors before going outdoors, using indoor space for gross motor activities, higher staff-per-child ratios, the presence of outdoor fixed equipment, and increased number of outdoor spaces with natural ground coverings were positive correlates of young children's PA [109, 110]. In European studies, other correlates, such as active opportunities in CC, larger size of indoor area per child, and the location of preschool building on the playground (i.e. sides of building with direct access to indoors when playing outdoors) have been linked to PA and/or SB in preschool children [111-113]. Clearly, there is a great deal of variation between countries and settings. Therefore, more recent and higher quality studies and additional studies outside the US are needed to explore correlates and determinants across all domains of the socio-ecological model in preschool children [92, 114].

1.5. Aim of the thesis

Establishing healthy weight and health-promoting PA behaviours in preschool years is paramount for optimal development. Many individual and environmental factors influence health outcomes in young people. However, research in young children is ever evolving, and more knowledge is needed to understand the complex associations between early life health behaviours such as PA and the development of adiposity.

The main aims of the present thesis are to investigate 1) the relationship between PA and SB with adiposity from both cross-sectional and longitudinal perspectives and 2) the CC correlates of PA, SB, and adiposity in young preschool children. To achieve this, the work is divided into three parts corresponding to three different publications within one study.

1. Association of physical activity with adiposity in preschoolers using different clinical adiposity measures: cross-sectional analysis (Study A)

Aim: To determine the cross-sectional associations of objectively measured PA and SB with adiposity in a large sample of 2-6-year-old preschoolers using three practice-based clinical adiposity measures: BMI, SF and WC. We were further interested in evaluating the impact of different epoch lengths (15-s vs 60-s) and vectors (uni-axial vs tri-axial).

Hypothesis: In young children, higher levels of TPA and VPA are associated with lower levels of adiposity: lower BMI, lower SF, and lower WC. Also, children classified as OW or OB show lower levels of PA and higher levels of SB than NW children.

2. Childcare correlates of physical activity, sedentary behaviour, and adiposity: a cross-sectional analysis of the SPLASHY study (Study B)

Aim: To identify a broad range of CC correlates of PA, SB, and adiposity in a large sample of 2-6-year-old preschoolers.

Hypothesis: Based on the socio-ecological model of health behaviour, demographic/biological and environmental variables are the main CC correlates of PA, ST, and adiposity.

3. Association of physical activity and sedentary time with adiposity in preschoolers using different clinical adiposity measures: a prospective analysis of the SPLASHY study (Study C)

Aim: To investigate whether PA and ST measured objectively at baseline predict adiposity 1 year later and if the relationship is bidirectional in a large sample of 2-6-years old preschoolers.

Hypothesis: Baseline PA levels, especially higher intensity PA, predict adiposity levels 1 year later independently of baseline values. Also, baseline levels of adiposity predict PA levels 1 year later independently of baseline values.

2. METHODOLOGY

2.1. Swiss Preschoolers' Health Study (SPLASHY)

The aim of the Swiss Preschoolers' Health Study (SPLASHY) is to examine the role of stress and PA on children's psychological and physiological health, particularly on cognitive function, psychological well-being, motor skills, and adiposity in children at an early stage of childhood. The SPLASHY study is a multi-site prospective cohort study including 555 preschool children aged 2 to 6 years within two sociocultural areas of Switzerland, the German- and French-speaking parts (clinical trial registry: ISRCTN41045021). Preschool children were recruited from 84 childcare centres within five cantons of Switzerland (Aargau, Bern, Fribourg, Vaud, Zurich), which together comprised 50% of the Swiss population in 2013. Recruitment lasted from January 2013 to October 2014. The detailed study design and the overall objectives have been published previously [115]. Baseline participants included 476 children aged 3-4 years, and follow-up data were collected 12 months later from 382 children who had participated at baseline (20% immediate drop-out) and 79 new children. The study was approved by all local ethical committees (No 338/13 for the Ethical Committee of the Canton of Vaud as the main ethical committee). Parents provided written informed consent, and children provided oral consent. Data collection was conducted in parallel at all study sites according to standardized procedures.

2.2. SPLASHY physical activity and sedentary behaviour assessment

Children's PA and ST were monitored objectively using a tri-axial accelerometer (wGT3X-BT, ActiGraph, Pensacola, Florida, USA). Children were asked to wear the accelerometer around the right hip continuously for seven consecutive days, including at night. The device was removed for activities involving water, such as showering or swimming. Children, parents, and CC staff received detailed instructions on the use of the activity monitor. PA data (raw data) were collected at a sampling frequency of 30 Hz, downloaded in 3-s epochs. For data analysis, periods of 20 minutes and more of consecutive zero readings were removed from the data and considered as non-wear time. All recordings between 9pm and

7am were excluded as this most likely reflected the hours spent sleeping. Days with a minimum of 10 hours' recording were considered valid days. Epoch length was set at 60 seconds to determine the level of total PA (TPA) as mean accelerometer counts per minute (cpm), light PA (LPA; min/day), moderate PA (MPA; min/day), moderate-to-vigorous PA (MVPA; min/day), vigorous PA (VPA; min/day) and ST (min/day). Moderate-to-vigorous PA and ST were defined as ≥3908 counts/60-s and ≤819 counts/60-s respectively; these are Butte et al.'s cut-points [55], which were developed specifically for preschool children using the same accelerometer model as in our study. We also used a 15-seconds epoch length to determine the level of TPA, LPA, MPA, MVPA, VPA, and ST. Moderate-to-vigorous PA and ST were defined as ≥420 counts/15-s and ≤24 counts/15-s respectively; these are Pate et al.'s cut-points [116], which were developed specifically for young children. Measurements across at least 3 days (2 weekdays and 1 week-end day) was considered valid accelerometry data. Data collection and processing criteria were based on a recent review [50].

2.3. SPLASHY adiposity assessment

Three different adiposity measures (BMI, WC, and SF) were performed in the CC centre by five well-trained examiners (CL, AZ, KS, AA, NM). Age-and-sex specific BMI z-scores (WHO) and percentiles were calculated, and overweight and obese (OW/OB) were defined based on the WHO [10] and on the IOTF (only percentiles) [25] criteria. The WHtR was also calculated to correct for growth-related changes in WC [40, 41]. Skinfold thickness was measured at the triceps, biceps, subscapular, and suprailiac crest. The sum of all four skinfolds was calculated and referred to as SF.

2.4. SPLASHY childcare environment assessment

In our study, the correlates of the CC environment were mainly assessed through a modified NAP SACC questionnaire. We included additional variables to the NAP SACC items in this CC questionnaire to gain a more detailed picture. These enquired about the parental home situation, child's social network with the CC, language region of the CC, rural or urban CC, and low-high socioeconomic status of the CC (see Study B for more details). We used the socio-ecological model of health behaviour proposed by Sallis et al. [90] to conceptualize these potential correlates. Correlates were selected and then classified into five domains: demographic/biological, psychological/cognitive/emotional, behavioural, sociocultural, and physical environment [90].

2.5. Personal SPLASHY contribution

SPLASHY is multi-centre cohort study involving four research groups composed of specialists from a range of disciplines: psychologists, an endocrinologist, physiologists, paediatricians, researchers, and students. Effective partnership among all collaborators is paramount to successfully perform such an interdisciplinary multi-site study. As a distinct member of the research group, I was mainly responsible for the coordination and implementation of all aspects of the testing in the Lausanne centre. In addition, I concurrently supervised and trained three master students. I also contributed to the other publications, where I am not the first author, by performing data collection and critically revising, editing, and approving the manuscripts for intellectual content. A full list of the Splashy publications is provided in Appendix V.

3. PUBLICATION A – Association of physical activity with adiposity in preschoolers using different adiposity measures: a cross-sectional study.

Authors: **Amar Arhab**, Nadine Messerli-Bürgy, Tanja H. Kakebeeke, Kerstin Stülb, Annina Zysset, Claudia Sabrina Leeger-Aschmann, Einat Avital Schmutz, Andrea H. Meyer, Simone Munsch, Susi Kriemler, Oskar G. Jenni, Jardena J. Puder

Submitted in ***BMC pediatrics***. To be found in Appendix III.

Contribution: The candidate contributed to data acquisition and played the main role in data analyses and in writing and finalizing the manuscript.

Abstract

Background: More research is needed about the associations between physical activity (PA) and sedentary behaviour (SB) with adiposity in preschoolers, particularly using more direct clinical measures of adiposity. Therefore, the main objective of this study was to investigate the cross-sectional association of objectively measured PA and SB with adiposity in a large sample of 2-6-year old preschoolers using different practice-based clinical adiposity measures: body mass index (BMI), skinfold thickness (SF), and waist circumference (WC). Furthermore, we were interested in evaluating the impact of different epoch lengths (15-s vs 60-s) and vectors (uni-axial vs tri-axial).

Methods: A total of 476 predominantly normal weight (NW; 77%) 2-6-year-old preschool children participated in the Swiss Preschoolers' Health Study (SPLASHY). PA was measured using accelerometers and was analysed using 15-sec (uni-axial) and then also 60-sec (tri-axial) epochs using validated cut-offs. Adiposity measures included body mass index (BMI), the sum of four skinfolds, and waist circumference (WC).

Results: After adjusting for age and sex, total PA and several PA intensities were positively and SB was inversely associated with BMI both in the total sample and in the NW children (all $p \leq 0.03$). Total and vigorous PA were inversely and SB was positively associated with SF in overweight and obese children (OW/OB; $p \leq 0.05$). Moderate and moderate-to-vigorous PA were positively associated with WC in the total sample and in the NW children (p≤0.01). Adjustment for potential sociocultural and biological confounding variables attenuated some of the results. Using 60-s (tri-axial vector) epochs showed less pronounced associations with BMI and WC but more pronounced inverse associations with SF.

Conclusions: In this very young and predominantly normal-weight population, PA is positively related to BMI and WC, but this relationship is not observed in OW and OB children. In this latter population, PA is inversely and SB is positively related to SF. Skinfold thickness could represent a useful and simple clinical measure of body fat in preschoolers. Sedentary behaviour and vigorous PA may play an important role in the development of childhood obesity.

4. PUBLICATION B – Childcare correlates of physical activity, sedentary behaviour, and adiposity in preschool children: a cross-sectional analysis of the SPLASHY study

Authors: **Amar Arhab**, Nadine Messerli-Bürgy, Tanja H. Kakebeeke, Kerstin Stülb, Annina Zysset, Claudia Sabrina Leeger-Aschmann, Einat Avital Schmutz, Andrea H. Meyer, Simone Munsch, Susi Kriemler, Oskar G. Jenni, Jardena J. Puder

Submitted in ***BMC Public Health***. To be found in Annex IV.

Contribution: The candidate contributed to data acquisition, assisted in data analyses in tight partnership with the collaborating statistician, and played the main role in writing and finalizing the manuscript.

Abstract

Background: The childcare (CC) environment can influence young children's physical activity (PA), sedentary behaviour (SB), and adiposity. However, knowledge is lacking regarding the impact of sociocultural correlates on these health outcomes. The aim of the study was to identify a broad range of CC correlates of PA, SB, and adiposity in a large sample of 2-6-years old preschoolers.

Methods: A total of 84 CC centres participated in the Swiss Preschoolers' Health Study (SPLASHY). Based on the socio-ecological model of health behaviour, 35 potential CC correlates were selected for the following domains: demographic/biological, psychological/cognitive/emotional, behavioural, socio-cultural, and physical environment. PA was measured by accelerometry. Outcome measures included total PA (TPA), moderate-to-vigorous PA (MVPA), SB, body mass index (BMI), and skinfold thickness (SF). PA measures consisted of both PA during CC days (full day attendance) and overall PA (including all days, both home and CC days).

Results: A total of 476 preschool children (mean age 3.9±0.7 yrs; 47% girls, 23% overweight and obese) participated in the study. Using multiple regression analysis, we identified the following CC correlates for higher TPA, higher MVPA or lower SB during CC days: older age, sex (boys), more frequent child-initiated interactions during CC, mixing different ages within a group, and the presence of a written PA convention in the CC centre (all $p \leq 0.02$). For higher overall TPA and/or MVPA or lower overall SB, including both home and CC days, correlates were: older age, sex (boys), more frequent child-initiated interactions during CC, mixing different ages within a group, parental PA involvement in the CC centre, and having a larger surface area in the CC centre (all $p \leq 0.046$). Correlates for lower SF were: sex (boys) and parental PA involvement in the CC centre (all $p \leq 0.02$). For lower BMI, only increased age ($p=0.001$) was a correlate.

Conclusions: More frequent child-initiated interactions and mixing different ages in CC, the presence of a written PA convention and/or a larger CC centre surface are correlates of PA and SB during CC days, and mostly also for overall PA. Parental involvement in CC centre PA projects was a correlate for reduced body fat. In Switzerland, demographic/biological, psychological, and sociocultural factors are CC correlates of preschoolers' PA, SB, and adiposity.

5. PUBLICATION C – Association of physical activity and sedentary time with adiposity in preschoolers using different clinical adiposity measures: a prospective analysis of the SPLASHY study

Authors: **Amar Arhab**, Nadine Messerli-Bürgy, Tanja H. Kakebeeke, Kerstin Stülb, Annina Zysset, Claudia Sabrina Leeger-Aschmann, Einat Avital Schmutz, Andrea H. Meyer, Simone Munsch, Susi Kriemler, Oskar G. Jenni, Jardena J. Puder

Contribution: The candidate contributed to data acquisition, assisted in data analyses in tight partnership with the collaborating statistician, and is currently preparing the manuscript for submission.

5.1. Abstract

Background: More prospective studies in preschool children using objective measures of physical activity (PA) and sedentary time (ST) and measures of central and total body fat are needed to define the role of PA in reducing future adiposity in children. The aim of this study was to investigate whether PA and ST measured objectively at baseline predicted adiposity 1 year later and whether the relationship was bidirectional in a large sample of 2-6-years old preschoolers**.**

Methods: A total of 555 predominantly normal-weight (NW; 77%) 2-6-year-old preschool children (age 3.9 ±0.7 yrs) participated in the Swiss Preschoolers' Health Study (SPLASHY) and were evaluated at baseline and 1 year later. PA was measured using accelerometers and was analysed using 60-sec (tri-axial) epochs. Adiposity measures included body mass index z-scores (BMI z-score), waist-to-height ratio (WHtR), and the sum of four skinfold thickness (SF). A cross-lagged panel model was used to determine the prospective associations between PA and ST with adiposity, adjusted for the baseline level of the measures.

Results: After adjusting for age and sex, baseline total PA (TPA) and moderate-to-vigorous PA (MVPA) predicted inversely WHtR 1 year later (all $p \leq 0.01$). The inverse association between baseline MVPA and future WHtR was independent of ST. Vigorous PA (VPA) predicted inversely BMI z-score and WHtR 1 year later (both $p \leq 0.03$). Baseline ST did not predict any future adiposity measures before (all $p \geq 0.09$) or after adjustment for MVPA (all $p \geq 0.68$). Baseline adiposity measures did not predict PA or ST 1 year later (all $p \geq 0.05$).

Conclusions: In this young and predominantly NW population, TPA and higher intensity PA are protective against the development of adiposity, whereas ST seems less important in this age group. In this longitudinal analysis, adiposity measures do not predict future PA.

5.2. Introduction

The global obesity epidemic has become a critical public health threat. The obesity epidemic also affects young children. The World Health Organisation (WHO) report on ending childhood obesity recommends the promotion of physical activity (PA) in the early years [4]. Cross-sectional studies have shown a strong inverse association between objectively measured PA and adiposity in children and adolescents [117, 118]. Furthermore, PA is favourably associated with health and wellbeing in youths, and more PA, in terms of duration, intensity, and/or frequency, is better than less PA for health promotion [13]. However, prospective studies have concluded that objectively measured PA may not be a key determinant of adiposity gain in school children and adolescents [119].

In preschool children, a recent systematic review of prospective studies showed an inverse association between total PA (TPA) and overweight (OW) [15]. Indeed, the review indicated that more research using objective measures of PA is needed to more definitively establish the relationships between PA of all intensities and health indicators, including adiposity, in young children [13]. Data are also lacking regarding various aspects such as sedentary behaviour (SB) and the relationship between PA and body composition. Furthermore, higher levels of SB are associated with adverse health effects (adiposity, metabolic syndrome, cardiovascular disease, poor psychological health, poor academic achievement, and low fitness) in cross-sectional and prospective studies in children and adolescents [17, 18]. Additionally, the effect sizes are small to very small, and there is little to no evidence of a causal relationship [17, 120]. On the other hand, moderate evidence exists for a prospective positive association between SB and OW in preschool children [15]. Most studies on SB used TV viewing as a proxy for SB, which may not be representative of all sedentary activities that occur throughout the day [18]. Additionally, most studies used body mass index (BMI) as a proxy of adiposity, which might not be sufficiently sensitive to account for growth and the changes in lean and fat mass during the preschool years [15, 17]. Thus, additional higher quality prospective studies in preschool children using reliable and objective measures of sedentary time (ST) and measures of total and central body fat are needed to extend our knowledge of and evidence on the association between SB and adiposity.

No single study has yet addressed the issue of bidirectional relationships between objectively measured PA and SB with adiposity in preschool children [15]. Kwon et al. examined the association between baseline adiposity and subsequent PA levels in preschool children and showed that adiposity level may be a determinant of PA [121]. In older children and adolescents, a few studies have addressed the issue of bi-directionality and found that body composition predicted PA [122-125] and SB [126] but not vice versa. However, other prospective studies did not find any association between PA and adiposity in this age group [119, 127-129]. It seems that this mutual relationship between PA and adiposity may vary during the developmental process and become more pronounced in some populations. These inconsistent results in older children and adolescents and the lack of studies in preschool children investigating the bi-directional relationship between PA and adiposity lead us to further investigate the magnitude and direction of longitudinal associations between PA and SB with adiposity, which are very relevant for preventive and therapeutic approaches.

The main aim of this study was to determine the prospective bi-directional associations between objectively measured PA and ST with adiposity in a large sample of 2-6-year-old preschoolers using different clinical measures of adiposity: BMI z-score, waist-to-height ratio (WHtR), and skinfold thickness (SF).

5.3. Methods

5.3.1. Study sample and design

The Swiss Preschoolers' Health Study (SPLASHY) is a multi-site prospective cohort study involving 555 (476 baseline participants & 79 new participants at follow-up, see below) preschool children within two sociocultural areas of Switzerland, the German- and French-speaking parts (clinical trial registry: ISRCTN41045021). Preschool children were recruited from 84 childcare centres within five cantons of Switzerland (Aargau, Bern, Fribourg, Vaud, Zurich), which together made up 50% of the Swiss population in 2013. Recruitment started between January 2013 and October 2014 when children were 2-6 years old. The detailed study design and the overall objectives have been described previously [115]. Baseline participants included 476 children aged 3-4 years, and follow-up data were collected 12 months later from 382 children who had participated at baseline (20% immediate drop-out) and 79 new children. The sample of 79 new children assessed during the follow-up was slightly younger (0.23 years based on mean) than the sample of the 476 children at baseline. Therefore, the 79 new children were added to the baseline data and their scores for follow-up were imputed. The study was approved by all local ethical committees (No 338/13 for the Ethical Committee of the Canton of Vaud as the main ethical committee). Parents provided written informed consent.

5.3.2. Assessment of physical activity and sedentary time

Children's PA and ST were objectively monitored using a tri-axial accelerometer (wGT3X-BT, ActiGraph, Pensacola, Florida, USA). Children were asked to wear the accelerometer around the right hip continuously for seven consecutive days including at night. The device was removed for activities involving water, such as showering and swimming. Children, parents, and childcare staff received detailed instructions on the use of the activity monitor. PA data (raw data) were collected at a sampling frequency of 30 Hz, downloaded in 3-s epochs. For data analysis, periods of 20 minutes and more of consecutive zero readings were removed from the data and considered as non-wear time. All recordings between 9pm and 7am were excluded as this most likely reflected the hours spent sleeping. Days with a minimum of 10 hours' recording were considered valid days. Epoch length was set at 60 seconds to determine the level of TPA as mean accelerometer counts per minute (cpm), moderate-to-vigorous PA (MVPA; min/day), vigorous PA (VPA; min/day), and ST (min/day). Moderate-to-vigorous PA and ST were defined as ≥3908 counts/60-s and ≤819 counts/60-s, respectively; these are Butte et al.'s cut-points [55], which were developed specifically for preschool children using the same accelerometer model as in our study. Furthermore, research has shown that accelerometer models are not interchangeable and recommends following the same data processing criteria (i.e. 60-s epoch) as the validation and calibration study [50, 130]. For their validation, Butte et al. used a direct method of room calorimetry and cross-calibrated their cut-points with energy expenditure measured by the indirect method of doubly labelled water under free-living conditions [55]. Additionally, these accelerometer cut-points are the only ones validated for 60-s epoch tri-axial vectors in preschool children [50]. Measurements across at least 3 days (2 weekdays and 1 week-end day) were available for 461 (83%) children, valid accelerometry data was not gathered from the remaining 94 (17%) children: for 45 children, one valid measurement day was available, and no PA measures were gathered from 49. Data collection and processing criteria were based on a recent review [50]. Thus, the final analysis for the current study was based on the 461 children for whom valid accelerometry data (2 weekdays and 1 week-end day) was available.

5.3.3. Assessment of adiposity

Three different adiposity measures (BMI z-scores, WHtR, and SF) were performed in the childcare centre by five well-trained examiners (CL, AZ, KS, AA, NM). Height was measured to the nearest 0.1 cm with a stadiometer and weight to the nearest 0.1 kg (Seca, Basel, Switzerland) using standardized procedures. BMI was then calculated as weight/height squared (kg/m^2). All measurements were taken barefoot and in light clothing. Age-and-sex-specific BMI z-scores (WHO) and percentiles were calculated and overweight and obese (OW/OB) were defined based on the WHO [10] and on the International Obesity Task Force (IOTF; only percentiles) [25] criteria, respectively. Waist circumference (WC) was measured in duplicate without clothing midway between the iliac crest and the lowest border of the rib cage to the nearest 0.1cm with a flexible tape. The WHtR was then calculated to correct for growth-related changes in WC [40, 41]. Skinfold thickness was measured in triplicate using standard procedures [131] to the nearest 0.1mm with Harpenden calipers (HSK-BI, British

Indicators, UK) at the triceps, biceps, subscapular, and suprailiac crest. The sum of all four skinfolds was calculated and referred to as SF.

5.3.4. Statistical analysis

Descriptive statistics were calculated using means ±SD for both baseline and 1-year follow-up characteristics for the whole sample and for boys and girls separately. Student's *t*-test for paired samples was used to examine differences between baseline and follow-up characteristics. For weight status differences between baseline and follow-up, we used the marginal homogeneity test. All exposure and outcome variables were checked for normal distribution, and only VPA needed to be ln-transformed.

To assess the longitudinal associations between PA (TPA; MVPA; VPA) and ST with adiposity, a cross-lagged panel model [132] was run (see Figure 7). It included the variables for PA and adiposity measured at each of the two waves. In accordance with most previous studies that tested the associations between PA and adiposity, we controlled for the children's age and sex. We were particularly interested in the cross-lagged coefficients (e.g., from PA at baseline to adiposity at 1-year follow-up and vice versa, see thick arrows in Figure 7). Each model was analysed with and without the adjustment for the respective baseline values of the outcome variable, since the consequences of such adjustments in analyses of change are complex and depend critically on several assumptions [133]. Additionally, since ST and SB have emerged as risk factors for adiposity, when MVPA was the exposure of interest we also added baseline ST as a covariate variable. When ST was the exposure of interest, we also added baseline MVPA as covariate. Both adjustments were performed to determine the independent associations of PA and ST with adiposity measures. Statistical level was set at $P<0.05$. All descriptive analyses were performed using IBM SPSS version 24.

To run the cross-lagged panel model, we used the R package lavaan [134], including robust standard errors according to the Huber-White method. To account for missing values, all cases were included in the analysis by using the full information maximum-likelihood approach, which is more efficient and leads to unbiased estimates provided that the missing pattern is either missing completely at random (MCAR) or missing at random (MAR).

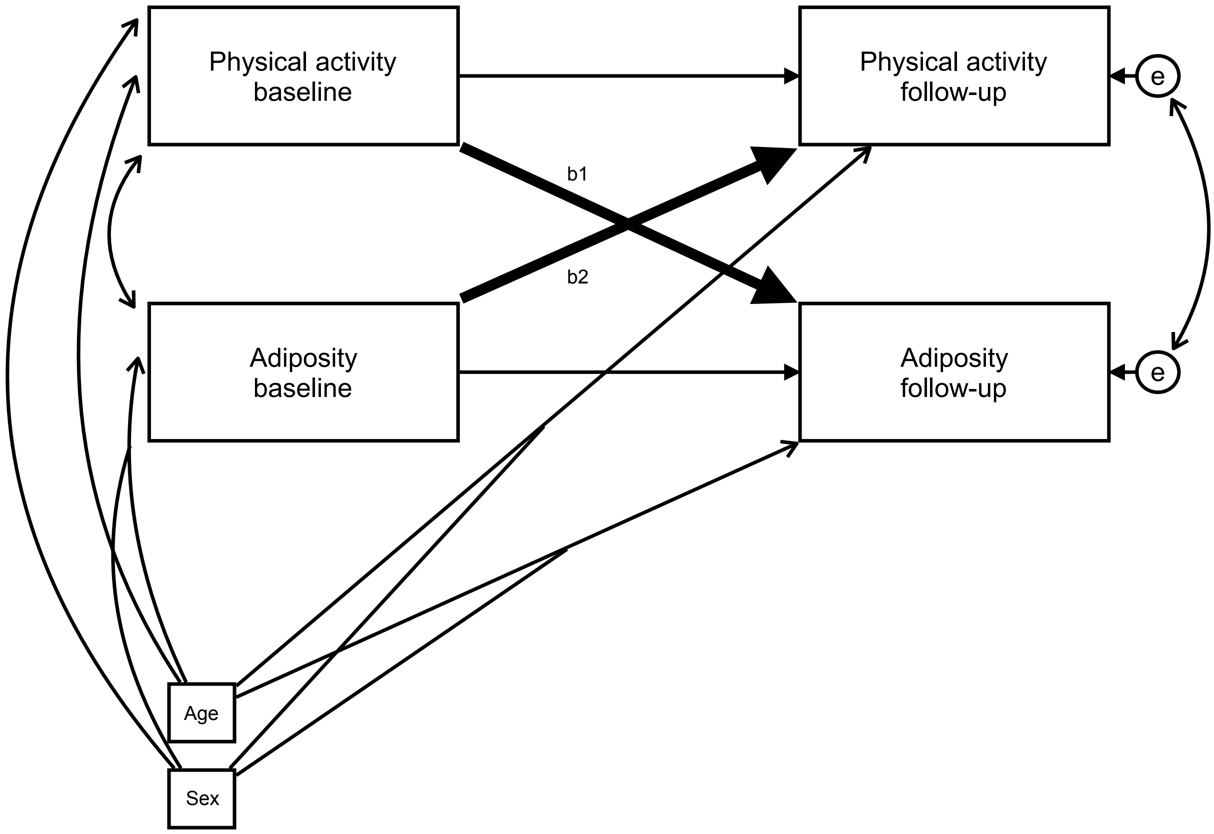

Figure 7. Cross-lagged model examining the longitudinal relationship between physical activity and adiposity. The current analyses focused on the b1 and b2 relationships. e= error term.

5.4. Results

The descriptive characteristics at baseline and 1-year follow-up for all children and for boys and girls separately are summarized in Table 5. Baseline mean age was 3.9 ± 0.7 years, and 47% of the participating children were girls. All children exhibited a significant increase in weight, height, BMI, and WHtR after 1 year (all $p \leq 0.01$). For PA measures, there was a significant increase in TPA, MVPA and VPA and a significant decrease in ST (all $p \leq 0.01$), which was explained by the changes in boys only. The prevalence of OW and OB based on the IOTF criteria did not change significantly among all children (all $p \geq 0.11$). The prevalence of OW and OB based on the WHO criteria did not change in the whole group, but decreased among girls ($p=0.04$).

Table 5. Characteristics, body composition, and physical activity characteristics of the population stratified by sex

	Total population			Boys			Girls		
Characteristics	**Baseline (n=461)**	**Follow-up (n=307)**	**p**	**Baseline (n=251)**	**Follow-up (n=171)**	**p**	**Baseline (n=210)**	**Follow-up (n=136)**	**p**
Demographic									
Age (years)	3.9 ±0.7	4.9 ±0.7	<.001	3.9 ±0.7	4.9 ±0.7	<.001	3.8 ±0.7	4.8 ±0.7	<.001
Body composition									
Weight (kg)	16.9 ±2.5	19.0 ±2.8	<.001	17.2 ±2.6	19.1 ±2.8	<.001	16.5 ±2.3	18.9 ±2.8	<.001
Height (cm)	102.4 ±6.3	109.4 ±6.1	<.001	103.2 ±6.6	109.7 ±6.3	<.001	101.6 ±5.9	109.0 ±5.9	<.001
BMI (kg/m^2)	16.0 ±1.4	15.9 ±1.5	.01	16.1 ±1.3	15.8 ±1.4	.14	16.0 ±1.5	15.9 ±1.6	.03
BMI z-score*	0.43 ±0.98	0.35 ±0.96	.10	0.46 ±0.95	0.36 ±0.95	.85	0.41 ±1.02	0.33 ±0.97	.02
WC (cm)	51.8 ±3.5	52.8 ±3.5	<.001	51.8 ±3.4	52.9 ±3.3	<.001	51.8 ±3.7	52.7 ±3.8	.001
WHtR	0.51 ±0.04	0.48 ±0.03	<.001	0.50 ±0.03	0.48 ±0.03	<.001	0.51 ±0.04	0.48 ±0.03	<.001
Skinfold (mm)	25.9 ±5.5	25.6 ±6.5	.17	24.4 ±4.8	24.0 ±5.6	.06	27.5 ±5.8	27.5 ±7.1	.92
Weight status based on WHO criteria			.16			.95			.04
Overweight, n (%)	81 (18)	52 (14)		48 (19)	27 (16)		40 (20)	17 (13)	
Obese, n (%)	23 (5)	15 (4)		11 (5)	7 (4)		12 (6)	7 (5)	
Weight status based on IOTF criteria			.17			.11			.67
Overweight, n (%)	40 (9)	27 (9)		15 (6)	10 (6)		25 (12)	17 (13)	
Obese, n (%)	10 (2)	5 (2)		5 (2)	3 (2)		5 (2)	2 (2)	
Physical activity									
TPA (cpm)	1413 ±270	1435 ±249	.01	1448 ±273	1491 ±238	.001	1370 ±260	1366 ±246	.91
MVPA (min/d)	76 ±34	82 ±32	<.001	82 ±35	91 ±31	<.001	68 ±30	71 ±30	.18
VPA (min/d)	5 ±5	6 ±4	<.001	5 ±6	6 ±4	.001	5 ±4	5 ±4	.19
ST (min/d)	240 ±52	235 ±52	.01	241 ±51	233 ±52	.01	238 ±53	237 ±53	.34

Total population is based on children with valid accelerometer data. Differences between baseline and follow-up were tested by paired Student's *t*-test. Weight status differences between baseline and follow-up were tested using the marginal homogeneity test.
BMI= body mass index; WC= waist circumference; WHtR= waist-to-height ratio; TPA= total physical activity; MVPA= moderate-to-vigorous physical activity; VPA= vigorous physical activity; ST= sedentary time; cpm= counts per minute; min/d= minutes per day.
*Based on the WHO criteria.
Cut-points for the physical activity intensities are based on Butte et al. (60-s epoch and tri-axial vector magnitude).

Age-and-sex adjusted prospective associations between baseline PA and ST with follow-up BMI z-score, WHtR, and SF are presented in Table 6. After adjustment for the baseline values of adiposity measures, TPA at baseline was negatively associated with WHtR at follow-up (p=0.01), but not with BMI z-score or SF (all p≥0.05). Moderate-to-vigorous PA at baseline was negatively associated with WHtR at follow-up (p=0.003), but not with BMI z-score or SF (all p≥0.91). For example, each additional 10 minutes of MVPA at baseline was associated with a reduction of 0.12 unit of WHtR 1 year later (p=0.003). The association between baseline MVPA and follow-up WHtR was also independent of baseline levels of ST (p=0.02, data not shown). Vigorous PA was negatively associated with BMI z-score and WHtR (all p≤0.03), but not with SF (p=0.52). Light PA was not associated with any of the adiposity measures (all p≥0.21, data not shown). Sedentary time was not associated with any of the three adiposity outcomes (all p≥0.09). These associations remained unchanged when data were adjusted for baseline levels of MVPA (p≥0.68, data not shown).

We then modelled BMI z-score, WHtR, and SF as exposures. Age-and-sex-adjusted associations between baseline adiposity measures with follow-up PA and ST are presented in Table 7. After adjustment for the baseline values of PA and ST, none of the adiposity measures at baseline were associated with PA and ST at follow-up (all p≥0.05). This was independent of further adjustment for time spent in MVPA or ST (p≥0.41, data not shown).

We also performed bi-directional analyses without adjustment for baseline values (PA and adiposity), and the results were very similar except for SF (either as exposure and outcome). Baseline TPA and all PA intensities were negatively associated with SF 1 year later (all p≤0.02, data not shown in detail), but baseline ST was not associated with SF (p=0.38). When SF was modelled as the exposure, baseline SF was associated negatively with MVPA 1 year later (p=0.01). Indeed, SF for all children did not change significantly between baseline and follow-up (see Table 1, p=0.17). Furthermore, SF measures between baseline and at follow-up were highly correlated (r=0.83, p<0.001).

Table 6. Age-and-sex-adjusted prospective associations of baseline physical activity and sedentary time with future adiposity.

	BMI z-score		WHtR		SF	
	β-coefficient (95% CI)	P-value	β-coefficient (95% CI)	P-value	β-coefficient (95% CI)	P-value
TPA (cpm)	-0.03 (-0.05, 0.00)	.05	-0.001 (-0.002, 0.00)	**.01**	0.02 (-0.15, 0.20)	.79
MVPA (min/d)	-2.24 (-4.50, 0.01)	.05	-0.12 (-0.19, -0.04)	**.003**	0.85 (-13.50, 15.20)	.91
#VPA (min/d)	-8.58 (-16.19, -0.97)	**.03**	-0.37 (-0.62, -0.12)	**.003**	-15.32 (-6.21, 3.15)	.52
ST (min/d)	0.91 (-0.20, 2.02)	.11	0.04 (-0.01, 0.08)	.09	1.41 (-7.40, 10.22)	.75

Data are shown using 60-s epoch tri-axial vector.
Analyses are adjusted for the baseline adiposity measures, age, and sex.
Data are shown per changes in 100cpm and per 10min intervals for the time at the respective intensities.
BMI= body mass index; WHtR= waist-to-height ratio; CI= confidence interval; TPA= total physical activity; MVPA= moderate-to-vigorous physical activity; VPA= vigorous physical activity; ST= sedentary time; cpm= counts per minute, min/d= minutes per day.
#values are ln-transformed.

Table 7. Age-and-sex adjusted prospective associations of baseline adiposity with future physical activity and sedentary time.

	TPA (min/d)		MVPA (min/d)		#VPA (min/d)		ST (min/d)	
	β -coefficient (95% CI)	p	β-coefficient (95% CI)	p	β-coefficient (95% CI)	p	β-coefficient (95% CI)	p
BMI z-score	-0.11 (-0.39, 0.17)	.44	-0.13 (-0.45, 0.19)	.44	-0.01 (-0.09, 0.08)	.89	0.26 (-0.41, 0.93)	.45
WHtR	-2.61 (-10.75, 5.52)	.53	-0.95 (-10.94, 9.04)	.85	0.04 (-2.81, 2.89)	.98	5.35 (-12.69, 23.38)	.56
SF	0.02 (-0.03, 0.07)	.39	0.02 (-0.04, 0.07)	.56	0.02 (0.00, 0.03)	.05	-0.01 (-0.12, 0.09)	.78

Data are shown using 60-s epoch tri-axial vectors.
Analyses are adjusted for the baseline physical activity measures, age, and sex.
Data are shown per changes in 100cpm and per 10min intervals for the time at the respective intensities.
TPA= total physical activity; MVPA= moderate-to-vigorous physical activity; VPA= vigorous physical activity; ST= sedentary timer; CI= confidence interval; BMI= body mass index; WHtR= waist-to-height ratio; SF= skinfold thickness; cpm= counts per minute, min/d= minutes per day.
#values are ln-transformed.

5.5. Discussion

In this large and very young sample of predominantly NW preschoolers, we found that baseline TPA and time spent in MVPA predicted reduced WHtR and VPA predicted reduced BMI z-score and WHtR 1 year later, while baseline time spent in ST did not predict any adiposity measure. In contrast, baseline adiposity measures did not predict future PA or ST. Our findings suggest that TPA and activities of at least moderate intensity (>3 METs) at an early age are protective against the development of adiposity.

The prospective negative associations between TPA, MVPA and VPA with adiposity in our study support the conclusion of a recent review that TPA is inversely associated with OW in preschool children [15]. Similarly, our results agree with results from the Iowa Bone Development Study performed in preschoolers, which that used quantile regression analysis to show that young children maintaining a high degree of vigorous activity and overall activity were less likely than peers to be in the upper quartile for adiposity at follow-up [87, 135]. A study by Butte et al. showed that higher MVPA and TPA level were associated with normal growth and accretion of fat-free mass in preschoolers [136]. In addition, Moore et al. showed that higher levels of accumulated PA over a 7-year period were associated with less body fat (BF) later (age 11 years) [137]. Similar to our study, they used sums of SF to assess adiposity [137]. However, we failed to find an association between PA and SF changes (i.e. SF at 1-year follow-up adjusted for baseline SF). We hypothesize that this is because BF did not change between baseline and follow-up and because correlations between baseline and follow-up SF were very high. Indeed, all PA measures were associated with future SF in our study (which is the sum of baseline SF and changes in SF over 1 year) when we did not adjust for baseline SF. Furthermore, the difference in length of follow-up is considerable between our study (1 year) and Moore et al.'s (7 years), which may also explain the disparities in results. In contrast, four studies did not find any association between PA and adiposity in preschool children [138-141]. Three of these studies used self-report to measure PA [139-141], and one study did find a prospective association between PA and metabolic health, but not between PA and BMI or fatness [138]. Our results support the protective role of more intense PA levels in reducing unhealthy weight gain in the early years. Furthermore, the protective effect of MVPA was independent of time spent in ST, suggesting that ST is less influential than MVPA in relation to adiposity. Bearing in mind that different studies used different cut-points to define MVPA, the magnitude of associations were stronger for more vigorous PA than for moderate levels of activity.

To our knowledge, no single study in preschool children has assessed the bi-directional associations between PA and ST with adiposity. In our study of predominantly NW preschoolers, we did not find a prospective association between baseline adiposity measures and PA 1 year later. In contrast, Kwon et al. showed that preschool children with low adiposity were more likely to be active at three-year follow-up than their peers with higher adiposity, suggesting that adiposity levels may be a determinant of lower levels of MVPA [121]. A prospective study in Danish children aged 8 to 11 years old found that fatness predicted decreased PA and increased ST, but not vice versa [126], Similarly, data from the International Children's Accelerometer Database for older children and adolescents showed that baseline abdominal adiposity (measured with WC) significantly predicted higher levels of ST 2 years later [142]. Disparities in results between our study and previous studies might be explained by differences in PA, ST, body composition assessment, and analytical procedures. Furthermore, the direction of association between PA and ST with adiposity may differ by age, by the baseline prevalence of obesity in the population (i.e. adiposity may affect PA more when children are more OW or obese at baseline), and by the energy balance profile of participants at follow-up [143]. All of these parameters affect the relationship between PA, and ST with adiposity during the developmental process and become more significant as children age. More detailed research is needed in preschool children to allow firm conclusions about the causality and direction of the relationship between adiposity and PA.

A review of prospective studies in preschool children has suggested a moderate positive association between SB, mainly TV viewing, and OW [15]. For example, Janz et al. showed that TV viewing was associated with follow-up adiposity and change in adiposity [135]. Similarly, Jago et al. demonstrated that BMI at 6-7-years of age was predicted by previous TV viewing [144]. In contrast, two recent studies showed no association between ST measured by accelerometry and later body composition and concluded that SB may not be an independent risk factor for obesity in preschool children [136, 145]. Likewise, the findings of the current study suggest that ST did not predict adiposity 1 year later. These observations remained unchanged when we adjusted for time spent in MVPA. Our results suggest that ST is not essential in this population and age group for the reduction of future adiposity. Three recent reviews of studies in older children and adolescents concluded that different types of SB are more important than the overall time spent sedentary in relation to health indicators, including adiposity [17, 18, 143]. Indeed, it appears that screen time behaviours showed more associations, but not objectively assessed total ST. Clearly, the diversity of exposures, outcomes, and research designs obscures the associations between SB and adiposity in children, and more detailed research is needed to examine potential mediating factors which complicate our interpretation.

5.5.1. Strength and limitations

Strengths of the current study included the relatively large sample size from regions that are representative of Switzerland. We also investigated a population that is younger than most cited studies, and this enables us to examine the relationship between health indicators early in the developmental process when the prevalence of pathology is still low. Moreover, we used objective methods to assess PA and SB, thereby avoiding the measurement errors and recall bias associated with self-reported measures. Outcome and exposure variables were analysed in their continuous form, decreasing the likelihood of the loss of statistical power that normally occurs when categorical variables are used. The inclusion of a range of valid and inexpensive clinical measures that represent various facets of adiposity represent further strengths of this trial. Finally, the prospective analyses allowed determination of the directionality of the associations between PA and SB with adiposity in predominantly NW preschoolers.

Some limitations should be noted. The time interval of 1 year between measurements was relatively short. Indeed, longer duration follow-ups are warranted to capture important changes in PA and ST during preschool and school-aged children and even during adolescence. Furthermore, we cannot rule out that results may be explained by residual unmeasured confounders (i.e. SES, sociocultural region, birth weight, sleep, and motor skills). Seasonal variations in PA and ST might have influenced the results (assessment during school year; autumn to spring), though children were measured exactly 1 year later. Finally, our study is limited by lack of data on dietary intake, which may have also affected the associations observed.

5.6. Conclusion

Our results show that higher levels of PA, especially of higher intensity, predicted lower adiposity 1 year later. Sedentary time was not associated with any of the adiposity measures. Adiposity did not predict PA and ST. Encouraging children to engage in PA of at least moderate intensity may be more important than reducing ST for preventing adiposity in healthy preschool children.

6. GENERAL DISCUSSION AND PERSPECTIVES

This thesis provides more insights into the complex relationship of physical activity (PA) and sedentary time (ST) with adiposity in young children. It also reveals novel correlates and confirms previous correlates of the childcare (CC) environment influencing PA behaviours and adiposity in preschool children.

Association of physical activity with adiposity

We showed that PA was associated with adiposity in both cross-sectional and longitudinal analyses. This is in line with previous reviews of cross-sectional [118, 146] and longitudinal data in preschool children [15, 87, 135-137]. Specifically, the cross-sectional results (Study A) showed that vigorous PA (VPA) was inversely associated with body fat (BF) in the total sample and in the overweight and obese (OW/OB; defined using WHO criteria, $\geq 85^{th}$ percentile) children. The particular importance of VPA has been reported in previous studies. For example, a study by Collings et al. showed that VPA was strongly inversely associated with BF measured by dual x-ray absorptiometry (DXA) in preschool children [146]. Similarly, numerous cross-sectional studies using DXA or air displacement plethysmography (ADP) have found an inverse association between VPA and BF in young children [135, 147-149]. Interestingly, we were able to replicate these findings using skinfold thickness (SF) as a measure of adiposity. Additionally, SF was shown to be highly correlated with total fat mass as measured by DXA in school-aged children, which reinforces its clinically convenient use in community-based studies involving young children [36]. Our longitudinal results (Study C) showed that baseline total PA (TPA) and moderate-to-vigorous PA (MVPA) predicted reduced waist-to-height ratio (WHtR) and VPA predicted reduced BMI z-score and WHtR 1 year later. We used WHtR and BMI z-scores instead of BMI and waist circumference (WC) to examine longitudinal changes in growth status [23]. However, there was no association between PA and SF. We hypothesize that this is because BF did not change between baseline and follow-up (see Table 5); correlation between baseline and follow-up SF was also very high ($r=0.83$, $p<0.001$). Indeed, all PA measures were associated with future SF, the sum of baseline SF and changes in SF over 1 year, in our study when we did not adjust for baseline SF. Similar to our longitudinal findings, previous longitudinal studies [87, 135, 137, 138] and a review of prospective studies [15] have shown higher levels of PA to be associated with lower adiposity in preschool children. For example, results from the Iowa Bone Development Study, performed in preschool children, showed that young children maintaining a high degree of vigorous activity and overall activity were less likely than their peers to be in the upper quartile for adiposity at follow-up [87, 135]. In accordance with previous data, our results support the protective role of more intense PA levels in reducing unhealthy body weight in the early years.

Furthermore, the association between PA and adiposity in preschool children seems to depend on the outcome measure of adiposity. Indeed, most studies that have used BMI to assess adiposity failed to find an inverse association, whereas studies that used percent BF as outcome measure for adiposity found evidence for an inverse association [118]. In comparison, our cross-sectional results (Study A) showed that PA was positively associated with BMI and WC. This relationship was especially pronounced in the normal weight (NW) group, but we found an inverse association between PA and SF, especially in the OW/OB group. These results suggest that BMI and WC alone do not adequately reflect adiposity and may be indicators of fat-free mass in healthy preschool children. Indeed, it has previously been shown that BMI’s accuracy as a measure of adiposity is limited, since BMI differences are largely driven by differences in fat-free mass [32], and fat-free mass is a stronger predictor of BMI than fat mass in thin children as measured by DXA [31]. Furthermore, most previous studies that have used BMI to measure adiposity in preschoolers have found no association between objectively measured PA and BMI and/or BMI z-score [144, 147, 149-154]. Misclassification of none or mild excess adiposity might have obscured the associations between PA and BMI, since most children were NW or OW rather than OB in these previous studies. Likewise, previous studies in preschool children using WC as a measure of adiposity showed inconsistent results. For example, one Finnish study found no associations between WC and PA [149]. Another study showed a positive association between sedentary behaviour (SB) and WC and inverse association between MVPA and WC in Portuguese girls above the 90^{th} WC percentile [155]. These suggest that WC might be an interesting and distinctive measure of visceral adiposity in preschoolers when OW or OB are present, but less so in a predominantly NW preschool population. We may conclude that BMI and WC are not ideal measures of excess BF in young and healthy preschoolers, in particular because BMI might be an indicator of fat-free mass in this healthy population, as previously shown in a study that used DXA [32, 33].

In summary, efforts to tackle paediatric OB may benefit from encouraging children to engage in VPA at an early age. Moreover, additional indices of body composition other than BMI are needed to better understand the relationship of PA and SB with adiposity in children. Thus, we showed that SF is a useful, simple, and inexpensive measure of adiposity. Our results contribute to the current understanding of the relationship between PA and adiposity in preschool children.

Association of sedentary behaviour/sedentary time with adiposity

Recently, SB and ST have emerged as risk factors for OW, OB, and other adverse health outcomes [17, 18]. Our results showed that ST was associated with BF in the cross-sectional analyses, but no prospective associations emerged. In agreement with our longitudinal results and opposite to our cross-sectional results, recent systematic reviews found no conclusive evidence for an association of adiposity with ST assessed using accelerometers [17, 18]. All studies reviewed assessed SB by accelerometry, and the outcome measures of adiposity were BMI, BMI z-scores, WC, and body composition measured by either bio impedance (BIA) or DXA. For instance, Collings et al. showed no cross-sectional associations between sedentary time and body composition measured by DXA, after adjusting for time spent in MVPA, in 4-year-old children in the UK [146]. Similarly, Buyn et al. found that accelerometry-derived SB was not associated with BMI z-score in two independent samples of preschool children [145]. Even though our cross-sectional results showed positive associations between ST and adiposity, the effect sizes were small, and the associations disappeared after adjustment for sociocultural (socio-economic index, language region) and biological (maternal BMI) confounding variables (see Study A). Moreover, the cross-sectional nature of these results precludes the inference of a causal relationship.

Our longitudinal results did not reveal a causal relationship between ST and adiposity in preschool children which is in line with most of the literature [17, 18]. For example, Biddle et al.'s meta-analytic review found no association in longitudinal studies and no evidence to support a causal association between SB and weight status in young people [17]. Similarly, van Ekris et al.'s review of purely prospective studies found no evidence of an association using objective assessments of SB with BMI, WC, and body composition [156]. Butte et al. found no association between ST measured by accelerometry and later body adiposity in preschool children [136]. Our results reinforce the evidence of no association between objectively measured ST and adiposity in children.

However, the majority of evidence specifically examined TV viewing as a measure of SB. Additionally, most studies used BMI as a marker of adiposity, which could have obscured the relationship. For example, a review of prospective studies in preschool children showed a moderate positive association between SB, mainly TV viewing, and OW [15]. Similarly, van Ekris et al. showed strong prospective evidence for an association of OW and OB with TV viewing but insufficient evidence for any association between TV viewing and other markers of adiposity [156]. Jago et al. showed that baseline levels of TV viewing predicted BMI 3 years later in preschool children [135, 144]. Supporting these findings, Janz et al. showed that baseline lower levels of TV viewing in preschool children were associated with less adiposity measured by DXA 3 years later [135]. Finally, Carson et al. concluded from numerous cross-sectional studies that TV viewing was associated with adiposity regardless of how it was measured (BMI, WC, DXA, etc.). A plausible explanation of this consistent association between TV viewing and adiposity could be the moderating effect of diet. Screen time (computer and video games) has been associated with less healthful eating [157], yet at least one review concluded that associations between SB and adiposity are not affected by diet [158]. However, the lack of causal evidence linking diet and screen time means that no clear conclusion can be drawn [17]. In addition, not all types of SB are equal. For instance, reading and homework are considered beneficial for academic achievement. Conversely, screen time is associated with lower self-esteem and negative conduct and social behaviours [18]. Hence, it is important to clearly identify the type of SB and its influence on adiposity when investigating associations of SB and ST with adiposity.

In summary, the associations between SB and adiposity differ by type of SB and marker of adiposity. Screen time behaviours, including TV viewing, are associated with adiposity, but objectively assessed ST is not. Moreover, although BMI has most often been studied, it is difficult to make clear comparisons between outcomes. Therefore, future studies should clearly identify outcome and exposure variables, and the precision of measurement of exposure and outcome variables should be taken into account when interpreting the results of studies.

Accelerometry data reduction

In Study A, we also investigated the impact of different epoch lengths and vectors on the association of PA and ST with adiposity. Despite the frequent occurrence of short bursts of activity in preschoolers, we found similar or even more pronounced results when using 60-s tri-axial epochs than when using 15-s uni-axial epochs. No previous study in preschool children has provided or compared different epoch lengths and vectors when investigating the association between PA and adiposity. However, applying different epoch lengths has been shown to lead to large and meaningful differences in PA and SB outcomes [49, 159]. For example, Colley et al. showed that 60-s epoch data recorded less MVPA and ST but more step counts, light PA (LPA), and TPA than 15-s epoch data [49]. Experts postulate that shorter epochs (i.e. 15-s of less) should be used for preschoolers to take account of their activity patterns [160, 161], yet only weak evidence exists to support this claim [48, 50]. Interestingly, most studies investigating the association between PA and adiposity in preschool children have used longer epochs (60-s) [135, 144, 146-148, 151-154, 162, 163]. Furthermore, our unpublished data suggest that the optimal epoch length may depend on the outcome of interest. For instance, short epochs might be better suited for capturing the extremely high and ultra-short acceleration peaks typical in bone-strengthening activities [164]. Conversely, longer epochs might be better suited for capturing the elevated energy-expenditure PA needed to reduce adiposity [50].

The existing 15-s cut-points to define PA intensities for this population were established by Pate et al. They are based on an older model of accelerometer than the one we used, and they were validated exclusively on a uni-axial vector (GT1M) [116]. Research has shown that the models are not interchangeable [50, 130]. In addition, a review concluded that tri-axial vector and accelerometers using the GT3X/+ model should be used to define physical activity energy expenditure (PAEE), which is the main variable of interest when investigating the relationship between PA and body composition [50]. Furthermore, the GT3X/+ model offers the only validation algorithm for PAEE and intensities in preschool children, and this is the same model that we used in our study [50]. Thus, we have adopted Butte et al.'s cut-points (60-s epoch, tri-axial vector). This is because 1) the cut-points are validated for the tri-axial vector and use a validated algorithm for PAEE in preschool children; 2) Butte et al. used the same model as we did; and 3) they applied the direct method of room calorimetry to validate the cut-points and cross-calibrated this by measuring energy expenditure using the indirect method of doubly labelled water under free-living conditions [55].

In summary, differences in accelerometer models (ActiGraph, Actiwatch, Actical), axes (one, two, or three axes), and epoch length selection (60-s or 15-s) can preclude comparison between studies. It is recommended to use the same accelerometer data reduction as the validation and calibration study of the accelerometer model used. Of note, we analysed the cross-sectional relationship between PA and ST with adiposity, and we obtained very similar results using 60-s epoch/tri-axial vector compared to 15-s epoch/uni-axial. Even so, standardization of PA behaviour analyses is urgently required in preschool children.

Bi-directional association between physical activity/sedentary time and adiposity

Our prospective findings showed that baseline adiposity measures did not predict future PA or ST in healthy preschool children. No single study in preschool children has previously assessed bi-directionality in the same study. However, Kwon et al. showed that preschool children one year older than our sample with lower baseline adiposity levels were more likely to be active (MVPA) at three-year follow-up than their peers with higher baseline adiposity, suggesting that adiposity levels may be determinant of lower levels of MVPA [121]. A Danish study in children aged 8-to-11-years-old examined the prospective association between PA and ST assessed by accelerometer and BF assessed by DXA [126]. In total, 785 children aged 7 years at baseline were followed for 200 days. The authors modelled the associations between baseline PA and change in BF by multiple linear regression adjusting for baseline values (baseline BF when PA was the exposure and vice versa) and multiple covariates (age, sex, pubertal status follow duration). The authors concluded that adiposity is a better predictor of PA and ST change than vice versa [126]. However, the longitudinal analyses were performed within a nutrition intervention study; this may have influenced changes in the energy density of the diet, thus influencing subsequent body composition. Similarly, data from the ICAD examining the prospective association between objectively measured ST and WC in 6413 children and adolescents concluded that neither ST nor MVPA predicted WC 2 years later after adjusting for baseline WC and additional confounders (sex, baseline age, baseline ST, monitor wear time, and follow duration) [142]. Additionally, baseline WC was not associated with MVPA at follow-up, and higher baseline WC was associated with increased ST. However, the degree of association was small and may not be clinically significant. A possible explanation for a reverse association could be that older (i.e. school age and older) OW children perceive their body image negatively, and this discourages them from PA or participation in sports. Sallis et al. showed that perceived body image was a correlate of PA [90]. Another possibility is that exercise causes pain or discomfort in OW children that puts them in disadvantage compared to NW children. However, more research is needed to draw firm conclusions.

In summary, the is the first study in preschool children investigating the bi-directional association between PA and adiposity. We showed that baseline adiposity did not predict PA or ST one year later. In older children, the relationship of PA and ST with adiposity may be either reverse or bidirectional. This in turn suggests that the relationship may vary during the developmental process and become more significant as children develop. However, paucity of data in preschool children prevents us from drawing clear conclusions. Therefore, more research is needed in preschool children.

Childcare correlates of physical activity, sedentary time and adiposity

In agreement with previous reviews, our results showed that CC correlates of PA and ST are multi-dimensional [90, 92, 94, 165]. We have identified child-initiated interactions with other children during CC, mixing different ages within a CC group, and the existence of a written PA convention as correlates of PA and ST. These novel correlates at the individual and sociocultural levels were not measured in previous studies, and thus could represent new ways of promoting positive PA behaviours in CC centres. Previous observations in preschool children indicate that many educators provide little encouragement to children to participate in PA [78, 107]. Hence, the children themselves create opportunities to interact with each other and engage in PA. Additionally, in line with the theory of observational learning, younger children may look up to older children and mimic their behaviours, which may encourage them to engage in positive PA behaviours [166]. We also found that child-initiated interactions with other children during CC, mixing different ages with a CC group, and a larger CC surface had an impact on overall PA and ST beyond the CC environment. Additionally, we found that parental PA involvement in PA projects at the CC centre was related with higher overall ST. The latter might indicate a compensatory response behaviour outside the CC environment. It could be that parents perceive that the CC centre provides adequate activity and thus let their children rest or engage in more sedentary activities when at home [111, 167]. However, the literature is very limited in this field, and only one study examined CC correlates' impact over the 24-hour day: Copeland et al. found that time provided outdoors and total active time were associated with higher overall PA throughout the entire 24-hour day [168]. Nevertheless, further studies are needed to accumulate evidence and better understand the influence of specific characteristics of the CC centre beyond its setting.

We also included body composition as outcome, since this is understudied in the literature of CC correlates. We found that being older was associated with lower BMI and that boys and parental PA involvement in PA projects of the CC were associated with reduced BF.

The importance of parental involvement in changing children's lifestyles and increasing motor skills has been reported in previous successful family-based [169, 170] and CC [102] interventions. These suggest that improving fundamental movement skills through parental involvement in CC is successful and can lead to lower BF [46]. In our study, parental involvement in the PA projects of the CC centre could simply be a marker of increased overall parental commitment. The only study that looked at correlates of adiposity in preschool children found that fewer opportunities for sedentary activities, fewer minutes spent in SB, more time spent in active play, and fewer offers of high fat/high sugar foods in CC were all associated with lower BMI or a lower risk of being OW [168]. That study was conducted in the US, used wristwatches to measure PA, and performed an observational assessment of the CC environment. Thus, cultural differences between the US and Switzerland and methodological discrepancies make comparison difficult.

Furthermore, we identified age and sex as correlates of PA and ST in preschoolers, which is line with consistent and strong evidence that boys are more active than girls and that older children are more active than younger children [90, 92, 94, 165]. Although age and sex cannot be modified, it is important that programmes and environments are designed to provide equal opportunities for all children. Furthermore, educators at CC centres should provide intentional opportunities for younger children and girls to engage in active play.

In summary, demographic/individual, psychological and sociocultural factors in Switzerland were CC correlates of preschoolers' PA, ST, and adiposity. Encouraging spontaneous interactions between children of different age groups and implementing a written convention that defines objectives, means, and or policies regarding PA should be integrated within the strategies of CC centres. Promoting these positive PA behaviours may well impact overall PA, and it is overall PA that is related to improved health outcomes.

Strengths and limitations

The strengths of the current thesis, part of the larger SPLASHY study, included the relatively large, randomly selected sample of preschool children from two cultural regions of Switzerland. We also investigated a population that is younger than most cited studies, which enabled us to examine relationships between health indicators early in the developmental process when the prevalence of pathology is still low. Further, we used objective methods to assess PA and SB, thus avoiding the measurement errors and recall bias associated with self-reported measures. Outcome and exposure variables were analysed in their continuous forms, decreasing the likelihood of the loss of statistical power that normally occurs when categorical variables are used. The inclusion of several valid and inexpensive clinical measures that represent different facets of adiposity represents a further strength of this thesis. Finally, the prospective analyses allowed determination of the directionality of the associations of PA and SB with adiposity in predominantly normal-weight preschoolers.

Limitations included the voluntary nature of study participation and the focus on children attending CC centres, which may have led to a potential participation bias. Another limitation is a lack of long-term assessment of the observed effects. Indeed, longer duration follow-ups are warranted to capture important changes in PA and ST in preschool and school -aged children and even during adolescence. Furthermore, accelerometers do not provide information on activity type or context. The inclusion of a proxy report by parents and educators would have allowed such information to be collected. Also, we cannot rule out the possibility that some results may be explained by residual confounding due to unmeasured confounders (i.e. SES, sociocultural region, birth weight, sleep, and motor skills). Seasonal variations in PA and ST might have influenced the results (assessment during school year; autumn to spring), although children were exactly measured 1 year later. Finally, our study is limited by lack of data on dietary intake, which may have also affected the observed associations.

Perspectives for implementation

The benefits to children's health and wellbeing of sufficient levels of PA are undeniable. Our findings highlight the importance of promoting higher levels of PA, specifically of MVPA intensity, in preschool children. This is particularly significant in the light of consistent evidence that MVPA begins to decline from around the age of school entry [171] and that SB increases with age in school-age children and adolescents by approximately 30 min daily SB per year

[172]. Furthermore, at least one study has suggested that 6 or 7 yrs is the critical age at which TV viewing and physical activity may affect BMI [144]. Since preschool children in the developed world lead highly sedentary lives that predispose them to OW and OB, promoting PA participation in the early years is crucial. However, intervention studies that have focused solely on PA have yielded little success in either increasing PA levels or decreasing adiposity in preschool children [173]. Furthermore, no single intervention can halt the rise of the growing OB epidemic. The WHO commission on ending childhood OB established six recommendations: 1) implement comprehensive programmes that promote the intake of healthy foods and reduce the intake of unhealthy food; 2) implement comprehensive programmes that promote PA and reduce SB; 3) integrate and strengthen guidance for noncommunicable disease prevention with current guidance for preconception and antenatal care; 4) provide guidance on and support for healthy diet, sleep, and PA in early childhood for optimal development; 5) implement comprehensive healthy school environments, health and nutrition literacy, and PA among school-aged children and youth; and 6) provide family-based, multicomponent lifestyle weight management services for children who are obese [4]. Clearly, OB-prevention interventions using multicomponent and multilevel approaches involving governments and schools, business and non-profit organisations, neighbourhoods and communities, individuals and families are warranted to support these recommendations. Beyond that, a shift in social norms is also required to overcome the childhood OB epidemic similar to the shift in attitudes towards and regulations governing smoking and tobacco. For the moment, future longitudinal studies in preschool children (before fat accumulation can hinder PA) are needed to address the issue of bi-directional or reverse causality. Other influences on energy balance are also likely to influence the preschool period, including the influence of diet, parental feeding style, and genetic predispositions, but discussion of these issues is beyond the scope of this thesis. One clear gap in the literature is the lack of evidence from outside the US, especially from the developing world. Since the OB epidemic has spread rapidly among children and adolescents in the developing world in recent years, more evidence is needed to understand its aetiology. In any case, public health efforts during the

preschool period should be aimed at preventing children from establishing obesogenic lifestyles and developing obesogenic growth trajectories.

Conclusion

Several factors influence energy imbalance which preclude using simplistic approaches to reduce childhood obesity. Still, we provided more evidence on the contributions of PA and SB to energy imbalance in preschool children. In the Swiss sociocultural context, we have identified specific childcare correlates of PA, SB, and adiposity that can be valuable targets for change in future interventions. Furthermore, encouraging participation in PA of at least of moderate intensity may be more important to public health than reducing SB for preventing obesity in healthy preschool children.

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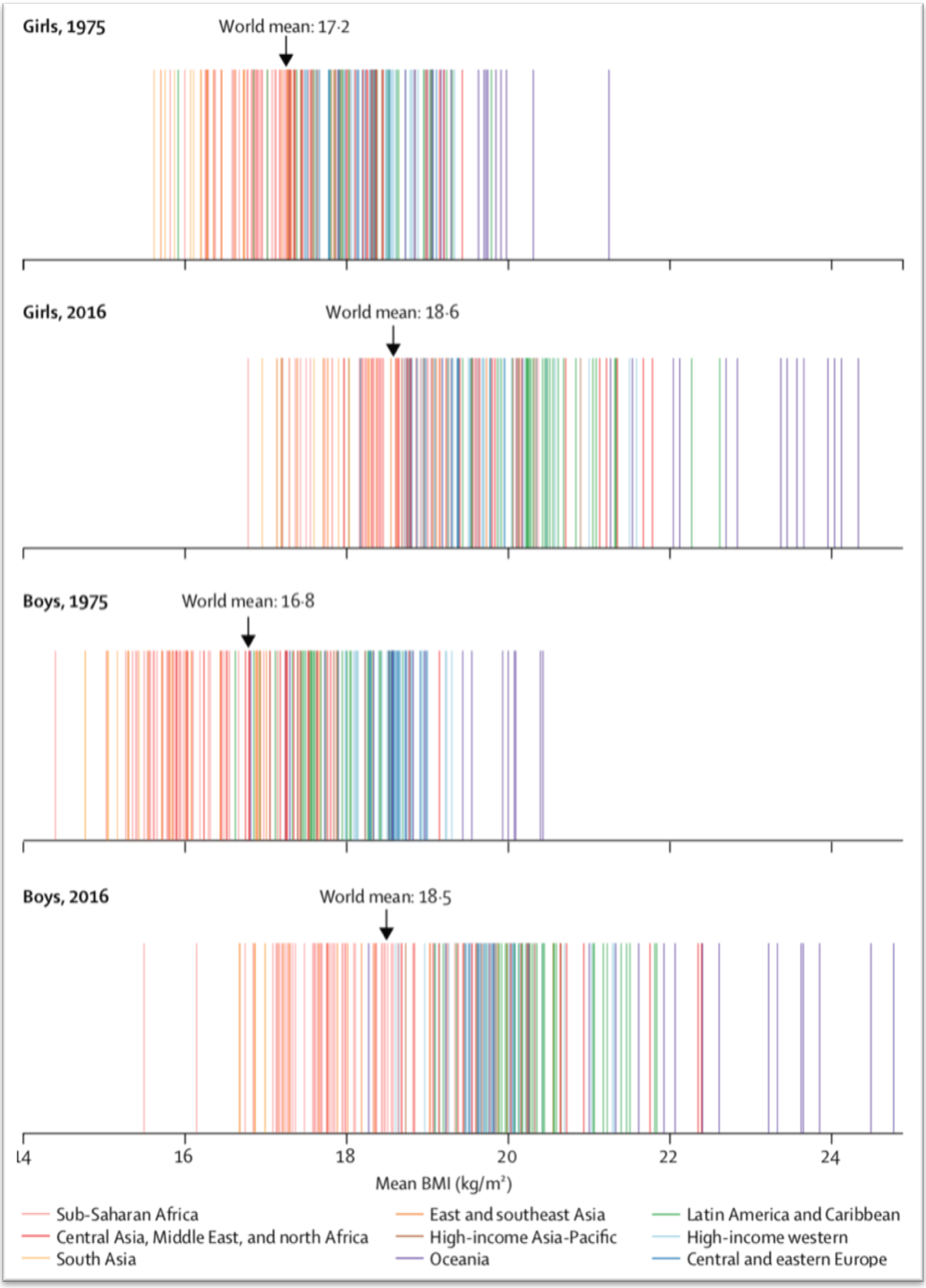
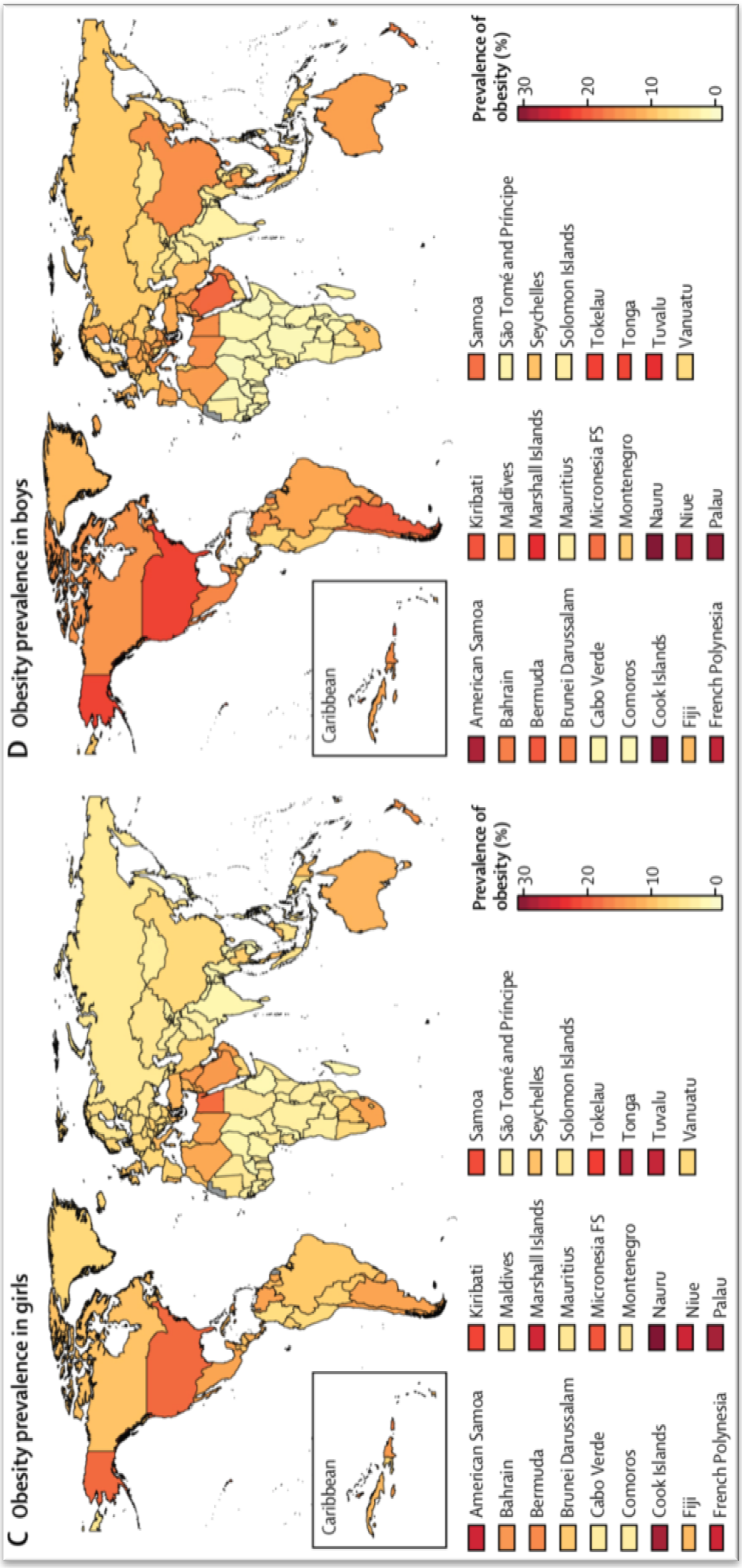
Appendix I

Figure A1. The age-standardized mean BMI in children and adolescents aged 5-19 years in 1975 and 2016. Each line shows one country.



Appendix II

Figure A2. The age-standardized prevalence of obesity in children and adolescents aged 5-19 years (Panel C – girls, Panel D – boys) in 2016. Obesity was defined as more than 2 SD above the median of the WHO growth reference



Appendix III

Association of physical activity with adiposity in preschoolers using different clinical adiposity measures: a cross-sectional study

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Abstract

Background: More research is needed about the association between physical activity (PA), sedentary behavior (SB), and adiposity in preschoolers, particularly using more direct clinical measures of adiposity. Therefore, the main objective of this study was to investigate the association between objectively measured PA and different clinical adiposity measures in a large sample of preschoolers using different epoch lengths and vectors (uni-axial vs tri-axial).

Methods: 476 predominantly normal-weight (NW; 77%) 2-6-year-old preschool children participated in the Swiss Preschoolers' Health Study (SPLASHY). PA was measured using accelerometers and was analyzed using 15-sec (uni-axial) and in a second step also 60-sec (tri-axial) epochs length using validated cut-offs. Adiposity measures included body mass index (BMI), the sum of four skinfolds, and waist circumference (WC).

Results: After adjusting for age and sex, total PA and different PA intensities were positively and SB was inversely associated with BMI in the total sample and in the NW children (all $p \leq 0.03$). Total and vigorous PA were inversely and SB was positively associated with skinfold thickness in overweight or obese children (OW/OB; $p \leq 0.05$). Moderate and moderate-to-vigorous PA were positively associated with WC in the total sample and in the NW children ($p \leq 0.01$). Additional adjustment for potential sociocultural and biological confounding variables attenuated some of the results. Using 60-s (tri-axial vector) epoch length showed less pronounced associations with BMI and WC, but more pronounced inverse associations with skinfold thickness.

Conclusions: In this very young and predominantly normal weight population, PA is positively related to BMI and WC, but this relationship is not observed in OW/OB children. In this latter population, PA is inversely and SB is positively related to skinfold thickness. Skinfold thickness could represent a useful and simple clinical measure of body fat in preschoolers. Sedentary behavior and vigorous PA may play an important role in the development of childhood obesity.

Keywords: Body composition; children; body mass index; accelerometry; SPLASHY.

Background:

The recent World Health Organisation (WHO) report about early obesity prevention measures in young children recommends the promotion of physical activity (PA) [1]. In school-aged children and adolescents, higher levels of PA have been shown to be protective against adiposity [2-4]. However, more research is needed in preschool children to better understand the association between objectively measured PA and adiposity, especially using body fat measures [5]. Methodological differences in assessing adiposity and PA make it difficult to compare and interpret different results [5].

The use of practice-based and inexpensive clinical measures of adiposity such as body mass index (BMI) as the most frequently used, skinfold thickness as a more direct measure of total body fat and waist circumference (WC) as a potential indicator of central body fat is primordial for utilization in larger studies and clinical practice. Most studies that have assessed the relationship between objectively measured PA and adiposity in preschoolers used BMI as a proxy of adiposity [6-20]. In doing so, the majority of studies found no association between PA and BMI [7, 8, 10-12, 15, 18-20]. Three studies found inverse association between PA and BMI [13, 16, 17]. On the other hand, three studies found a positive association [6, 9, 14]. For example, Espana-Romero et al. found a positive association between moderate-to-vigorous PA and BMI in boys only [6], while the other two studies found a positive association in the total sample. To our knowledge, two studies investigated the association between PA and WC in preschool children [6, 20]. The first study found no association [20], and the second study found a positive association with SB and a negative association with moderate-to-vigorous PA, respectively, but only among girls at the 90th WC percentile and higher [6]. We do not know of any studies investigating the associations of objectively measured PA with skinfold thickness in preschool children. However, many studies in preschoolers have used more complex and expensive measures like dual-energy X-ray absorptiometry (DXA) or air-displacement plethysmography (ADP) when assessing the relationship of PA with body fat [18, 20-23]. Thus, the use of simple and inexpensive clinical measures of total or central body fat such as skinfold thickness and WC are needed to draw firm conclusions along with direct methods to measure PA.

It has been suggested that specifically high-intensity PA improves body composition and prevents obesity in children, possibly by reducing stem cell differentiation into fat mass [24]. In accordance with this observation, five studies using DXA or ADP have found an inverse association between vigorous PA and body fat [18, 20-23]. In addition, young children's PA is highly intermittent, and is characterized by brief and sporadic bursts of energy [25]. Therefore, the use of short epoch of 15-s intervals of accelerometer recordings have been suggested, especially for higher intensities [26, 27]. Previous studies investigating the relationship between PA and adiposity in preschoolers have used primarily longer epoch (60-s) and no study compared the performance of different epochs regarding the association between PA and body composition [5]. On the other hand, longer epoch (60-s) would be more appropriate for metabolic outcomes, such as adiposity, where PA energy expenditure over an extended period is the variable of interest [28]. Furthermore, it is important to consider the multidimensional "chaotic" activity pattern of preschoolers. Thus, including not only uni-axial vector (only vertical axis; as done in almost all studies that investigated PA and adiposity in preschoolers), but also tri-axial vector could be especially pertinent regarding the aspect of PA energy expenditure and obesity.

The main aim of this study was to determine the cross-sectional association between physical activity with adiposity in a large sample of 2-6-year-old preschoolers using different practice-based clinical adiposity measures: BMI, skinfold thickness and WC. We were further interested in evaluating the impact of different PA intensities and sedentary behavior (SB) on adiposity and to test if we obtained different results when using different epoch lengths and different vectors (uni-axial vs tri-axial).

Methods:

Study sample and design

The Swiss Preschoolers' Health Study (SPLASHY) is a multi-site prospective cohort study including 476 preschool children within two sociocultural areas of

Switzerland (German and French speaking part) (ISRCTN41045021). Preschool children were recruited from 84 childcare centers within five cantons of Switzerland (Aargau, Bern, Fribourg, Vaud, Zurich), which together made up 50% of the Swiss population. Recruitment started between November 2013 and October 2014 when children were 2-6 years old. The detailed study design and the overall objectives have been previously described [29]. For the present analysis, children with no BMI data (n=13) were excluded. Thus, the final analysis included 463 children. The study was approved by all local ethical committees (No 338/13 for the Ethical Committee of the Canton of Vaud as the main ethical committee). Parents provided written informed consent. This current analysis focuses on the baseline cross-sectional data.

Assessment of PA

PA was objectively monitored using an accelerometer (w/GT3X-BT, ActiGraph, Pensacola, FL, USA). Children were asked to continuously wear the accelerometer around the hip for five weekdays and two weekend days. The device was removed for water-based activities, e.g. showing or swimming. Children, parents, and childcare staff received detailed instructions on the use of the activity monitor. PA data (raw data) were collected at a sampling frequency of 30 Hz, downloaded in 3-s epochs. For data analysis, periods of 20 minutes and more of consecutives zero readings were removed and considered as non-wear time. All recordings between 9pm and 7am were excluded as this most likely reflected the hours spent sleeping. Measurements with a minimum of 10 hours recordings were considered a valid day. In a first analysis, we analyzed all children with at least one valid day. In a second step, we only analyzed children according to stricter criteria including only children with at least 2 valid weekdays and one valid weekend day and compared these populations.

Epoch length was set at 15-seconds to determine the level of total PA as means accelerometer counts per minutes (cpm), and time spent in light PA, moderate PA, moderate-to-vigorous PA, vigorous PA, and SB. Moderate-to-vigorous PA and SB were defined as ≥420 counts/15-s and ≤24 counts/15-s, respectively, using Pate et al. cut-points [30], developed specifically for young children. These accelerometer cut-points are the only ones validated for 15-s in preschool children and are only validated for the uni-axial vector (vertical axis). For their validation, they used an indirect method of a portable metabolic system with a mask. On the other hand, Butte et al. [31] established the only validated, tri-axial vector cut-points for preschool children, but using 60-s epoch [28]. They used a direct method of room calorimetry plus cross-calibrated their cut-points by measuring energy expenditure by the indirect method of doubly labelled water under free-living conditions. Moderate-to-vigorous PA and SB were defined as ≥3908 counts/60-s and ≤819 counts/60-s, respectively, using Butte et al. cut-points [31]. Data collection and processing criteria were based on a recent review [28].

Assessment of adiposity

Three different adiposity measures (BMI, skinfold thickness, and WC) were performed in the childcare center by 5 different well-trained examiners (CL, AZ, KS, AA, NM). Height was measured to the nearest 0.1 cm with a stadiometer and weight to the nearest 0.1 kg (Seca, Basel, Switzerland) using standardized procedures. BMI was then calculated as weight/height squared (kg/m^2). All measurements were taken barefoot and in light clothing. BMI percentiles were calculated and overweight/obese (OW/OB) were defined based on the WHO [32] and on the International Obesity Task Force (IOTF) [33] criteria. Skinfold thickness was measured using standard procedures [34] in triplicate to the nearest 0.1mm with Harpenden calipers (HSK-BI, British Indicators, UK) at the triceps, biceps, subscapular, and suprailiac crest. The sum of all four skinfolds was calculated and referred to as “skinfold thickness or body fat”. Waist circumference was measured in duplicate without clothing midway between the iliac crest and the lowest border of the rib cage to the nearest 0.1cm with a flexible tape.

Potential confounding variables

Potential confounding variables known to be related to childhood obesity and PA were included. Socioeconomic status (SES) was calculated by coding the occupational status of both parents using the International Socio-Economic Index (ISEI) value [35]. Out of maternal and parental ISEI values the maximal SES was determined (ISEI max). Sociocultural regions were defined by language and geographical region (German speaking, versus French speaking, part of Switzerland) [36]. Parents filled out a general health questionnaire reporting the maternal weight and height which were used to calculate maternal BMI.

Statistical Analysis

Descriptive statistics were calculated using means ±SD for continuous variables, or percentages for categorical variables. All outcome variables were checked for normal distribution and only vigorous PA was log-transformed.

To assess the association between PA and adiposity, a multilevel model was also used with child and childcare center representing level one and two hierarchies, respectively. Predictors were total PA, time spent in the different PA intensities, and in SB. Each predictor was tested in a separate model. Outcomes were the three different measures of body composition. The model contained a random intercept for each childcare center.

We also tested if these associations were different between children with at least 1 valid day and the children who did have at least 2 valid weekdays and one valid weekend day of PA accelerometer measurements (n= 33 (8%) and n=392 (92% of all children who had BMI data), respectively). We did this by adding a dummy variable regarding these strict validity criteria to the model together with its interaction with the predictor PA. This allowed us to test whether less strict validity criteria (i.e. having one valid day of PA measurements) led to different estimated coefficients for PA. However, interaction terms for PA measures were not significant across all three body composition outcomes (all $p>0.14$) and estimates were always comparable between the two groups. In addition, groups did not differ in mean values of PA and body composition, except for higher WC and SB in the children fulfilling the strict valid PA data ($p<0.05$). We henceforth only report the results of the entire sample of children having at least one valid day of accelerometer measurements. Missing data were not imputed.

In accordance with most previous studies, analyses testing the associations between PA and adiposity were adjusted for the children's age and sex and represented the basic model. In a further step, we additionally adjusted for sociocultural (ISEI max, sociocultural region) and biological (maternal BMI) confounders.

As the fat-mass and fat-free mass content differ between preschoolers with normal weight (NW) and preschoolers with OW/OB, the relationship between PA and adiposity measures were also assessed in subgroup analyses according to weight status.

Analyses were performed using 15-s epoch and in a second step also using 60-s epoch. Results are shown for the 15-s epoch uniaxial (vertical axis only) using Pate cut-points [30]. Additionally, since preschoolers show a lot movement in the other two axes as well (not only the vertical axis; see above), and this might be important for overall physical activity energy expenditure, we also reported results for the 60-s epoch tri-axial using Butte [31] (see Additional file 1 for more detailed results using the 60-s epoch lengths). For the ease of interpretation, regression coefficients from all models were converted: coefficients were modified to represent the average unit change in the outcome per unit increase in the independent variable by simply multiplying it with 100 for total PA (per 100 counts per minute) and by 10 for the time spent in different PA and sedentary intensities (per 10 min). Statistical significance was set at $P < 0.05$ for all analyses.

Results:

The descriptive characteristics for all children are summarized in Table 1. Mean age was 3.9 ± 0.7 years and 47% of the participating children were girls. Overweight and obesity prevalence rates were 18% and 5% according to WHO [32] criteria and 9% and 2% according to the IOTF [33] criteria, respectively. All prevalence rates were similar between girls and boys (all $p \geq 0.75$).

Table 1. Descriptive characteristics of the participants stratified by weight status.

Characteristics	Total (n=463)	NW (n=357)	OW/OB (n=106)	P-value
Age (years)	3.9 ±0.7	3.9 ±0.7	3.8 ±0.8	0.13
Gender				
Boys, n (%)	246 (53)	190 (53)	56 (53)	0.94
Girls, n (%)	217 (47)	167 (47)	50 (47)	
Socioeconomic/cultural				
ISEI max.	61.8 ±16.1	61.8 ±15.7	61.8 ±17.4	0.73
Sociocultural region				
French speaking, n (%)	121 (26)	96 (27)	25 (24)	0.45
German speaking, n (%)	342 (74)	261 (73)	81 (76)	
Biological				
Maternal BMI (kg/m^2)	22.7 ±3.8	22.5 ±3.7	23.5 ±4.2	0.02
Body composition				
Body mass index (kg/m^2)	16.0 ±1.4	15.5 ±0.9	17.8 ±1.1	**<0.001**
Waist circumference (cm)	51.9 ±3.5	50.9 ±3.0	55.1 ±3.4	**<0.001**
Skinfold thickness (mm)	25.9 ±5.5	24.8 ±4.6	29.8 ±6.5	**<0.001**
Physical activity				
TPA (cpm)	624 ±155	620 ±146	636 ±176	0.51
LPA (min/d)	300 ±34	299 ±34	301 ±33	0.56
MPA (min/d)	70 ±20	69 ±19	71 ±21	0.33
MVPA (min/d)	92 ±30	91 ±29	95 ±34	0.39
VPA (min/d)	23 ±12	22 ±11	24 ±15	0.85
SB (min/d)	372 ±50	374 ±50	365 ±53	0.12

Total population is based on children with valid BMI data.
NW= normal-weight; OW/OB= overweight/obese; ISEI= international socio-economic index; BMI= body mass index; TPA= total physical activity; LPA= light physical activity; MPA= moderate physical activity; MVPA= moderate-to-vigorous physical activity; VPA= vigorous physical activity; SB= sedentary behavior; cpm= counts per minute; min/d= minutes per day.
Cut-points for the physical activity intensities are based on Pate [30].
Differences in baseline characteristics between NW and OW/OB were calculated using the WHO criteria [32].

Age- and sex- adjusted associations between PA and SB with BMI, skinfold thickness, and WC using the **15-s epoch uni-axial vector** are presented in Table 2a. In the total sample, total PA and time spent in light, moderate, and moderate-to-vigorous PA were positively associated with **BMI** ($p \leq 0.02$). For example, increasing total PA by 100 cpm/day or the time spent in moderate PA by 10 min/day were both associated with a 0.1 kg/m^2 higher BMI. Sedentary behavior showed an inverse relation with BMI (p=0.002). In the NW children, total PA and all PA intensities were positively associated and SB was inversely associated with BMI (all p≤0.03), while there were no associations in the OW/OB children.

There were no significant associations between the different PA measures and **skinfold thickness** in the total sample or in the NW children. However, in the OW/OB children, total (p=0.02) and vigorous PA (borderline sig, p=0.05) were inversely and time spent in SB was positively associated with skinfold thickness (p=0.03).

Moderate and moderate-to-vigorous PA were positively associated with **WC** in the total population and in the NW children (p≤0.01) and in addition light PA was associated with WC in the NW children (borderline sig, p=0.05). Similar to BMI, PA was not related to WC in the OW/OB children.

The associations between PA and adiposity after further adjustments for sociocultural and biological confounders are presented in Table 2b and show a slightly reduced sample size. After these adjustments, moderate and moderate-to-vigorous PA remained positively associated with BMI in the total sample and total PA and all intensities except for vigorous PA remained significant in the NW children (p≤0.05). Regarding skinfold thickness, SB remained positively associated with skinfold thickness in the OW/OB children (p=0.04), while the other associations were attenuated. Regarding WC, moderate and moderate-to-vigorous PA remained associated with WC in the total sample (p=0.01 and 0.05, respectively) and in the NW children (both p≤0.03).

Table 2. Associations between physical activity, sedentary behavior, and adiposity

a) Adjusted for age and sex.

BMI

	Total (n=425)		**NW (n=321)**		**OW/OB (n=104)**	
	β-coefficient (95% CI)	P-value	β-coefficient (95% CI)	P-value	β-coefficient (95% CI)	P-value
TPA (cpm)	0.10 (0.02, 0.20)	**.02**	0.10 (0.02, 0.20)	**.001**	0.01 (-0.10, 0.10)	.92
LPA (min/d)	0.05 (0.01, 0.10)	**.001**	0.05 (0.02, 0.08)	**.001**	-0.002 (-0.50, 0.10)	.96
MPA (min/d)	0.10 (0.05, 0.20)	**.001**	0.10 (0.05, 0.10)	**.001**	0.03 (-0.10, 0.20)	.58
MVPA (min/d)	0.10 (0.03, 0.10)	**.002**	0.10 (0.02, 0.10)	**.001**	0.01 (-0.10, 0.10)	.75
#VPA (min/d)	2.20 (-0.50, 4.80)	.11	2.20 (0.30, 4.20)	**.03**	-1.00 (-5.40, 3.30)	.64
SB (min/d)	-0.04 (-0.10, -0.02)	**.002**	-0.03 (-0.05, -0.01)	**.001**	-0.01 (-0.01, 0.03)	.50

Skinfold thickness

	Total (n=395)		**NW (n=300)**		**OW/OB (n=95)**	
	β-coefficient (95% CI)	P-value	β-coefficient (95% CI)	P-value	β-coefficient (95% CI)	P-value
TPA (cpm)	-0.20 (-0.50, 0.20)	.37	0.05 (-0.30, 0.40)	.80	-1.00 (-2.00, -0.10)	**.02**
LPA (min/d)	0.10 (-0.10, 0.20)	.27	0.10 (-0.05, 0.02)	.18	-0.10 (-0.50, 0.30)	.56
MPA (min/d)	0.10 (-0.20, 0.40)	.42	0.20 (-0.08, 0.40)	.18	-0.30 (-1.00, 0.30)	.33
MVPA (min/d)	-0.01 (-0.20, 0.20)	.92	0.04 (-0.10, 0.20)	.63	-0.30 (-0.70, 0.10)	.15
#VPA (min/d)	-6.80 (-17.40, -3.80)	.21	-1.60 (-11.80, 0.87)	.76	-23.80 (-47.60, 0.08)	**.05**
SB (min/d)	-0.004 (-0.10,0.10)	.86	-0.05 (-0.10, 0.04)	.28	0.30 (0.03, 0.50)	**.03**

Waist circumference

	Total (n=416)		**NW (n=314)**		**OW/OB (n=102)**	
	β-coefficient (95% CI)	P-value	β-coefficient (95% CI)	P-value	β-coefficient (95% CI)	P-value
TPA (cpm)	0.10 (-0.10, 0.40)	.18	0.20 (-0.05, 0.40)	.13	0.002 (-0.40, 0.40)	.99
LPA (min/d)	0.01 (-0.03, 0.20)	.18	0.10 (-0.001, 0.20)	**.05**	-0.10 (-0.20, 0.10)	.55
MPA (min/d)	0.30 (0.10, 0.40)	**.003**	0.30 (0.10, 0.40)	**.001**	0.10 (-0.30, 0.40)	.70
MVPA (min/d)	0.20 (0.04, 0.30)	**.01**	0.10 (0.03, 0.30)	**.01**	0.10 (-0.10, 0.30)	.52
#VPA (min/d)	4.80 (-1.90, 11.60)	.16	5.30 (-1.00, 11.70)	.10	2.80 (-9.90, 15.50)	.66
SB (min/d)	-0.04 (-0.10,0.02)	.18	-0.04 (-0.10, 0.02)	.17	0.03 (-0.10, 0.10)	.64

b) Adjusted for age, sex, sociocultural and biological confounding variables*.

BMI

	Total (n=391)		**NW (n=298)**		**OW/OB (n=93)**	
	β-coefficient (95% CI)	P-value	β-coefficient (95% CI)	P-value	β-coefficient (95% CI)	P-value
TPA (cpm)	0.01 (-0.03, 0.20)	.16	0.10 (0.001, 0.10)	**.046**	-0.02 (-0.10, 0.10)	.98
LPA (min/d)	0.03 (-0.01, 0.06)	.19	0.04 (0.01, 0.07)	**.001**	0.02 (-0.01, 0.05)	.60
MPA (min/d)	0.10 (0.02, 0.20)	**.01**	0.09 (0.04, 0.10)	**.001**	0.02 (-0.10, 0.10)	.72
MVPA (min/d)	0.06 (-0.01, 0.10)	**.02**	0.05 (0.02, 0.10)	**.001**	0.01 (-0.07, 0.10)	.79
#VPA (min/d)	1.40 (-1.40, 4.10)	.33	1.90 (0.20, 3.90)	.08	-0.90 (-5.40, 3.60)	.70
SB (min/d)	-0.02 (-0.05, 0.001)	.06	-0.02 (-0.04, -0.004)	**.02**	-0.001 (-0.05, 0.04)	.77

Skinfold thickness

	Total (n=362)		**NW (n=277)**		**OW/OB (n=85)**	
	β-coefficient (95% CI)	P-value	β-coefficient (95% CI)	P-value	β-coefficient (95% CI)	P-value
TPA (cpm)	-0.10 (-0.60, 0.20)	.37	0.10 (-0.30, 0.40)	.74	-0.70 (-1.00, -0.01)	.11
LPA (min/d)	0.10 (-0.10, 0.20)	.31	0.10 (0.10, 0.30)	.06	-0.10 (-0.50, 0.20)	.56
MPA (min/d)	0.10 (-0.20, 0.40)	.50	0.20 (-0.08, 0.50)	.15	-0.02 (-0.90, 0.50)	.60
MVPA (min/d)	-0.02 (-0.20, 0.20)	.85	0.05 (-0.10, 0.20)	.62	-0.10 (-0.60, 0.30)	.57
#VPA (min/d)	-8.90 (-20.40, -2.60)	.13	-3.00 (-14.20, 8.20)	.59	-16.70 (-41.20, -7.70)	.18
SB (min/d)	0.003 (-0.10, 0.10)	.96	-0.07 (-0.20, 0.04)	.19	0.20 (0.01, 0.50)	**.04**

	Waist circumference					
	Total (n=386)		**NW (n=294)**		**OW/OB (n=92)**	
	β-coefficient (95% CI)	P-value	β-coefficient (95% CI)	P-value	β-coefficient (95% CI)	P-value
TPA (cpm)	0.10 (-0.10, 0.30)	.45	0.10 (-0.10, 0.40)	.20	0.05 (-0.40, 0.50)	.83
LPA (min/d)	0.05 (-0.05, 0.10)	.29	0.08 (-0.01, 0.20)	.08	-0.03 (-0.20, 0.20)	.79
MPA (min/d)	0.20 (0.05, 0.40)	**.01**	0.30 (0.09, 0.40)	**.004**	0.10 (-0.30, 0.50)	.61
MVPA (min/d)	0.10 (0.0002, 0.30)	**.05**	0.10 (0.02, 0.30)	**.03**	0.10 (-0.10, 0.30)	.43
#VPA (min/d)	2.30 (-4.80, 9.40)	.53	3.90 (-2.90, 10.70)	.26	2.50 (-11.10, 16.10)	.72
SB (min/d)	-0.03 (-0.10, 0.04)	.43	-0.03 (-0.10, 0.03)	.33	0.005 (-0.10, 0.10)	.94

Data are shown using 15-s epoch uniaxial vector.
*Analyses are adjusted for age, sex, International Socio-Economic Index (ISEI), socio-cultural region, and maternal BMI.
Data are shown per changes in 100cpm and per 10min intervals for the time in the respective intensities.
NW= normal-weight; OW/OB= overweight/obese; CI= confidence interval; TPA= total physical activity; LPA= light physical activity; MPA= moderate physical activity; MVPA= moderate-to-vigorous physical activity; VPA= vigorous physical activity; SB= sedentary behavior; cpm= counts per minute, min/d= minutes per day.
Weight status, NW and OW/OB, were defined using the WHO criteria [32].
#values are log-transformed.

When using **60-s epoch tri-axial vector**, the relationships between PA and BMI or WC were similar or less pronounced for the total sample and for the NW children, while the inverse relationship between PA and skinfold thickness was more pronounced in the total sample and in the OW/OB children than when using 15-s epoch uni-axial vector (see Table S1 for more details). Thus, total PA was positively associated with **BMI** in the total sample and in NW children (p=0.03) and in addition moderate PA was positively and SB was inversely associated in the NW children (p≤0.03), while they were no associations in the OW/OB children. For **skinfold thickness**, vigorous PA was inversely associated with skinfold thickness in the total sample and in the OW/OB children (both p=0.001). Interestingly, the coefficients in the associations between vigorous PA and skinfold thickness in the OW/OB children were very similar when using the 60-s or 15-s epochs (β= -24.90 and β= -23.80, respectively). Additionally, total PA was inversely and SB was positively associated with skinfold thickness in the OW/OB children (p≤0.03). For **WC**, only moderate PA showed a positive association in the NW children (p=0.02). After further adjustments for sociocultural and biological confounders, most relationships between PA and adiposity were attenuated except between total PA and BMI in the NW children (p=0.02) and between vigorous PA and skinfold thickness in the total sample and in the OW/OB children (both p=0.01).

Discussion:

In this large and very young sample of predominantly NW preschoolers, we found that PA was positively related to BMI and to WC. This relationship was only observed in the NW, but not in the OW/OB children. Vigorous PA was inversely and SB was positively associated with skinfold thickness in the OW/OB children. When using 60-s (tri-axial vector) epoch instead of 15-s (uni-axial vector) epoch, we found similar results, but less pronounced associations with BMI and WC, but more pronounced inverse associations with skinfold thickness. Based on our results, we may conclude that BMI and WC are not an ideal measures of excess body fat in young and healthy preschoolers. Especially, BMI might rather be an indicator of fat-free mass in this population. On the other hand, skinfold thickness may represent a useful, valid and inexpensive research and clinical measure of body fat in this population.

Most previous studies using BMI to express adiposity in preschoolers found no significant relationship between objectively measured PA and BMI and/or BMI z-score [7, 8, 10-12, 15, 18, 20]. Since in the included studies most of the children were NW or overweight rather than obese, it’s possible that misclassification for none or mild excess adiposity obscured the association between PA and BMI. Three studies found an inverse association with BMI [13, 16, 17]. The reported differences between weight groups were often driven by very obese children at the “extreme” spectrum. Similar to our results, 3 studies found a positive association between PA and BMI [6, 9, 14]. For example, Espana-Romero et al. [6] reported a significant positive association between moderate-to-vigorous PA and BMI z-score in boys only with a BMI up to the 50th percentile. The authors suggested that the positive association maybe explained by greater fat-free mass among more active boys. Likewise, the positive association between PA and BMI in our study was only found in the NW children. In these NW children, BMI accuracy to measure adiposity is indeed limited and BMI differences are largely driven by differences in fat-free mass [37]. A study describing the relation of fat-free mass and fat mass to BMI, showed that in NW 5-8-year-old children fat-free mass was a stronger predictor of BMI than fat mass [38]. Thus, BMI reliability is uncertain for this age group to define adiposity, especially in the non-obese.

We found that PA, especially vigorous PA was negatively associated and SB was positively associated with skinfold thickness. These associations were observed in the OW/OB children. These results were even more pronounced and also seen in the total sample, when using 60-s (tri-axial vector) epoch, regardless of adjustments for multiple confounders. This epoch length might be particularly adapted for the assessment of physical activity energy expenditure [28]. Similarly, several studies using DXA or ADP found an inverse association and/or a positive association between vigorous PA and SB with body fat, respectively [18, 20-23]. However, it is not always suitable to use DXA or ADP in large epidemiological studies because of cost, irradiation exposure, and limited availability outside research settings [39]. Alternative methods such as skinfold thickness are more practical, especially as they highly correlate with DXA in children (r=0.90) [40]. Skinfold thickness could thus represent a very useful and simple measure of body fat in community-based studies and clinical practice involving preschoolers.

The particular importance of vigorous PA has been shown in previous studies using DXA. In a large cohort of British preschoolers, vigorous PA, but not other PA measures, was inversely associated with total and abdominal adiposity [21]. Similarly, several studies showed that children with higher vigorous PA had either lower body fat or were less likely to gain body fat compared to children with low vigorous PA levels [17, 22, 23]. We extended these results using skinfold measures and integrating confounder variables. Thus, vigorous PA may potentially play a key role in the obesity development already at an early age, by possibly reducing stem cell differentiation into fat mass [24].

As visceral adiposity is related to numerous cardiovascular and metabolic risk factors [41], we evaluated the use of WC as a potential measure of central body fat. We found a positive association between moderate and moderate-to-vigorous PA and WC in the total population and in the NW children, while no association was found in the OW/OB children. Two previous studies investigated this association in preschoolers, but children in both studies had higher WC measures compared to our sample. In contrast to our results, Leppänen et al. found no association between WC and PA, using wrist placement to capture PA [20]. The second study also did not find an association between PA and WC in the total sample. However, they found that among the subgroup of girls at and above the 90th WC percentile, a positive association between SB and WC and a negative association was observed between moderate-to-vigorous PA and WC [6]. It could suggest that WC might be an interesting and distinctive measure of visceral obesity in preschoolers when overweight or obesity are present, but less so in a predominantly NW preschool population. Furthermore, it is often difficult to reliably measure WC in young preschoolers because of frequent small changes in posture, abdominal inflation or deflation, low abdominal musculature, and as they get easily tickled.

Shorter epoch (15-s) is postulated to be more appropriate in young children because their patterns of PA are highly intermittent [26]. Despite this, most studies investigating the associations between PA and adiposity used longer epoch (60-s) [8-13, 15, 18, 21-23, 42]. No previous study provided and compared the performance of different epoch lengths and vectors (15-s uni-axial vs 60-s tri-axial) when investigating the association between PA and adiposity in this young population. The 60-s tri-axial analysis measures more than only the vertical movements and is especially adapted for studies where physical activity energy expenditure is important. Indeed, one previous study had used bi-axial and one tri-axial vector to look at PA and adiposity in preschoolers. Both had used wrist placement to capture PA which makes it more difficult to compare with our results. Using 60-s epoch (tri-axial vector) in our study, we found similar results than with the 15-s (uni-axial vector), but less pronounced associations with BMI and WC and more pronounced inverse associations with skinfold thickness. Thus, when studying metabolic outcomes such as adiposity or PA energy expenditure, using short epoch lengths (15-s, especially if uni-axial) may not provide a clear advantage, and more studies are needed.

To be able to compare with the majority of previous studies and to get a general overview, we adjusted our analyses in a first step only for age and sex. Additional adjustment for potential sociocultural and biological confounding variables attenuated some of the results, but also reduced the sample size.

Strength and limitations

Strengths of the current study included the relatively large sample size from regions that are representative of Switzerland. We also investigate a very young population that is younger than most cited studies which enables us to examine relationship between health indicators early in the developmental process when prevalence of pathology is still low. The inclusion of different valid and inexpensive clinical measures of adiposity represent further strengths of this trial. However, the cross-sectional design of the study precludes our ability to infer a causal relation between PA and adiposity in preschoolers. Additionally, the 15-s cut-points of the current study were established with an older model of accelerometer than the one we used and cut-points only exist for the uni-axial vector. Furthermore, newer research show that the models are not interchangeable [28, 43]. Performing multiple comparison could potentially lead to biases. However, testing both epochs and vectors helps us better understand the relationship between PA (and its nature) and outcomes such as body composition in this young population as we have to account for their short bursts of activities, their erratic movements in more than a vertical direction and also have to take into account the importance of physical activity energy expenditure. Finally, the short duration of PA spent in vigorous physical activity intensity might confound certain results. However, the duration of vigorous PA in the current study is very similar to other studies in preschoolers [21].

Conclusions:

In conclusion, we observed that in predominantly NW preschoolers PA was positively related to BMI and WC. This relationship was only observed in the NW, but not in the OW/OB children. Physical activity, particularly vigorous PA, was inversely related and SB was positively related to skinfold thickness in the OW/OB children. BMI and WC alone do not adequately reflect adiposity in this population, and BMI is possibly even an indicator of fat-free mass in healthy NW preschool children. Therefore, skinfold thickness or other direct measures of body fat are needed for research and clinical practice. Also, encouraging children to spend less time in SB and to engage more in vigorous PA at an early age may play a key role in obesity development. Prospective study designs are needed to further examine the association between PA and body composition in young children and to define the best measures to assess both PA and adiposity.

List of abbreviations:

WHO, world health organisation; PA, physical activity; BMI, body mass index; WC, waist circumference; DXA, dual-energy x-ray absorptiometry; ADP, air-displacement plethysmography; SB, sedentary behavior; IOTF, international obesity task force; SES, socioeconomic status; ISEI, international socio-economic index; NW, normal-weight; OW/OB, overweight/obese.

Declarations:

Ethics approval an consent to participate

The study was approved by all local ethical committees (No 338/13 for the Ethical Committee of the Canton of Vaud as the main ethical committee). Parents provided written informed consent.

Consent for publication

Not applicable.

Availability of data and materials

Data will not be shared, because it contains confidential information of participants.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

JP: designed research of the overall study in collaboration with SM-OJ-SK; JP: designed substudy and overall analysis and structure of the manuscript; AZ-CL-ES-KS-AA-NM-TK: conducted research; AM: assisted statistical analyses; AA: wrote the paper under the supervision of JP; SM-OJ-SK: commented the paper and adapted its content; AZ-CL-ES-KS-AA-NM-TK: contributed to data collection. All authors approved the final version of the manuscript. The last 4 authors* have a shared last authorship.

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Additional file

"Table S1" shows the "associations between physical activity, sedentary behavior, and adiposity stratified by weight status" using 60-s epoch tri-axial.

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Table S1. Associations between physical activity, sedentary behavior, and adiposity.

a) Adjusted for age and sex.

BMI

	Total (n=425)		NW (n=321)		OW/OB (n=104)	
	β-coefficient (95% CI)	P-value	β-coefficient (95% CI)	P-value	β-coefficient (95% CI)	P-value
TPA (cpm)	0.05 (0.01, 0.10)	**.03**	0.06 (0.02, 0.09)	**.03**	-0.01 (-0.08, 0.07)	.85
LPA (min/d)	0.01 (-0.01, 0.04)	.35	0.02 (0.004, 0.04)	.20	-0.01 (-0.06, 0.03)	.60
MPA (min/d)	0.03 (-0.01, 0.08)	.18	0.04 (0.005, 0.07)	**.03**	0.003 (-0.07, 0.08)	.95
MVPA (min/d)	0.03 (-0.01, 0.07)	.20	0.03 (0.003, 0.07)	.30	0.0001 (-0.07, 0.07)	.99
#VPA (min/d)	-0.50 (-1.80, 0.90)	.48	0.50 (-0.50, 1.5)	.33	-1.10 (-3.40, 1.10)	.32
SED (min/d)	-0.02 (-0.04, -0.01)	.15	-0.03 (-0.04, -0.003)	**.02**	-0.001 (-0.04, 0.04)	.96

Skinfold thickness

	Total (n=395)		NW (n=300)		OW/OB (n=95)	
	β-coefficient (95% CI)	P-value	β-coefficient (95% CI)	P-value	β-coefficient (95% CI)	P-value
TPA (cpm)	-0.08 (-0.30, 0.10)	.40	0.07 (-0.10, 0.30)	.48	-0.60 (-1.00, -0.20)	**.01**
LPA (min/d)	0.04 (-0.06, 0.15)	.44	0.04 (-0.07, 0.10)	.49	-0.01 (-0.30, 0.20)	.92
MPA (min/d)	-0.01 (-0.02, 0.10)	.51	0.01 (-0.20, 0.20)	.91	-0.30 (-0.70, 0.10)	.17
MVPA (min/d)	-0.10 (-0.30, 0.10)	.27	-0.002 (-0.20, 0.20)	.98	-0.30 (-0.70, 0.02)	.06
#VPA (min/d)	-8.80 (-14.20, -3.40)	**.001**	-1.70 (-6.90, 3.50)	.52	-24.90 (-36.40, -13.30)	**.001**
SED (min/d)	0.03 (-0.06,0.10)	.50	-0.02 (-0.10, 0.07)	.70	0.20 (0.03, 0.50)	**.025**

Waist circumference

	Total (n416)		NW (n=314)		OW/OB (n=102)	
	β-coefficient (95% CI)	P-value	β-coefficient (95% CI)	P-value	β-coefficient (95% CI)	P-value
TPA (cpm)	0.10 (-0.04, 0.20)	.20	0.10 (-0.02, 0.20)	.11	-0.02 (-0.20, 0.20)	.85
LPA (min/d)	0.02 (-0.05, 0.10)	.55	0.01 (-0.01, 0.10)	.11	-0.05 (-0.20, 0.10)	.40
MPA (min/d)	0.10 (-0.04, 0.20)	.19	0.10 (0.02, 0.20)	**.02**	0.10 (-0.10, 0.30)	.34
MVPA (min/d)	0.10 (-0.04, 0.20)	.25	0.10 (-0.04, 0.20)	.21	0.10 (-0.10, 0.30)	.44
#VPA (min/d)	-2.50 (-5.90, 0.97)	.16	0.20 (-3.10, 3.50)	.92	-3.60 (-10.10, 2.90)	.28
SED (min/d)	-0.01 (-0.10,0.05)	.83	-0.02 (-0.10, 0.04)	.47	0.05 (-0.10, 0.20)	.41

b) Adjusted for age, sex, sociocultural and biological confounding variables*.

BMI

	Total (n=391)		NW (n=298)		OW/OB (n=93)	
	β-coefficient (95% CI)	P-value	β-coefficient (95% CI)	P-value	β-coefficient (95% CI)	P-value
TPA (cpm)	0.03 (-0.02, 0.10)	.24	0.05 (0.01, 0.10)	**.02**	-0.02 (-0.10, 0.10)	.71
LPA (min/d)	0.002 (-0.02, 0.03)	.90	0.02 (-0.01, 0.04)	.14	-0.02 (-0.10, 0.03)	.48
MPA (min/d)	0.02 (-0.03, 0.07)	.46	0.03 (0.01, 0.10)	.10	-0.001 (-0.10, 0.10)	.98
MVPA (min/d)	0.01 (-0.03, 0.06)	.56	0.03 (-0.01, 0.10)	.11	-0.003 (-0.10, 0.10)	.94
#VPA (min/d)	-0.80 (-2.30, 0.60)	.25	0.20 (-0.80, 1.30)	.66	-0.95 (-3.50, 1.60)	.46
SED (min/d)	-0.002 (-0.03, 0.02)	.86	-0.01 (-0.03, 0.01)	.26	-0.01 (-0.04, 0.05)	.82

Skinfold thickness

	Total (n=362)		NW (n=277)		OW/OB (n=85)	
	β-coefficient (95% CI)	P-value	β-coefficient (95% CI)	P-value	β-coefficient (95% CI)	P-value
TPA (cpm)	-0.10 (-0.30, 0.10)	.48	0.10 (-0.10, 0.30)	.32	-0.40 (-0.90, 0.04)	.07
LPA (min/d)	0.03 (-0.10, 0.10)	.59	0.10 (-0.10, 0.20)	.31	0.02 (-0.20, 0.30)	.88
MPA (min/d)	-0.05 (-0.30, 0.20)	.64	0.04 (-0.20, 0.20)	.72	-0.03 (-0.40, 0.40)	.90
MVPA (min/d)	-0.10 (-0.30, 0.10)	.43	0.02 (-0.20, 0.20)	.82	-0.10 (-0.40, 0.30)	.70
#VPA (min/d)	-8.50 (-14.40, -2.60)	**.01**	-1.30 (-6.90, 4.40)	.66	-18.50 (-31.40, -5.50)	**.01**
SED (min/d)	0.04 (-0.10, 0.20)	.43	-0.03 (-0.10, 0.10)	.51	0.20 (-0.10, 0.40)	.15

	Waist circumference					
	Total (n=386)		**NW (n=291)**		**OW/OB (n=92)**	
	β-coefficient (95% CI)	P-value	β-coefficient (95% CI)	P-value	β-coefficient (95% CI)	P-value
TPA (cpm)	0.06 (-0.10, 0.20)	.43	0.10 (-0.04, 0.20)	.18	0.50 (-0.20, 0.30)	.68
LPA (min/d)	0.02 (-0.05, 0.10)	.59	0.05 (-0.02, 0.10)	.16	-0.02 (-0.20, 0.10)	.79
MPA (min/d)	0.10 (-0.10, 0.20)	.30	0.10 (-0.05, 0.20)	.26	0.20 (-0.10, 0.40)	.16
MVPA (min/d)	0.05 (-0.10, 0.20)	.39	0.10 (-0.05, 0.20)	.29	0.10 (-0.10, 0.30)	.19
#VPA (min/d)	-3.40 (-7.00, 0.30)	.07	-0.32 (-3.80, 3.20)	.85	-2.60 (-10.10, 4.80)	.48
SED (min/d)	0.002 (-0.10, 0.10)	.94	-0.01 (-0.10, 0.05)	.69	-0.004 (-0.10, 0.10)	.95

Data are shown using 60-s epoch tri-axial vector.
*Analyses are adjusted for age, sex, International Socio-Economic Index (ISEI), socio-cultural region, and maternal BMI.
Data are shown per changes in 100cpm and per 10min intervals for the time in the respective intensities.
NW= normal-weight; OW/OB= overweight/; CI= confidence interval; TPA= total physical activity; LPA= light physical activity;
MPA= moderate physical activity; MVPA= moderate-to-vigorous physical activity; VPA= vigorous physical activity; SED= sedentary time;
cpm= counts per minute, min/d= minutes per day.
Weight status, NW and OW/OB, were defined using the WHO criteria.
#values are log-transformed.

Appendix IV

Childcare correlates of physical activity, sedentary behaviour and adiposity in preschool children: a cross-sectional analysis of the SPLASHY study

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Abstract

Background: The childcare (CC) environment can influence young children's physical activity (PA), sedentary behaviour (SB), and adiposity. However, there is lack of knowledge regarding the impact of sociocultural correlates on these health outcomes. The aim of the study was to identify a broad range of CC correlates of PA, SB, and adiposity in a large sample of preschoolers.

Methods: 84 CC participated in the Swiss Preschoolers' Health Study (SPLASHY). Based on the socio-ecological model of health behavior, 35 potential CC correlates were selected according to the following domains: demographic/biological, psychological/cognitive/emotional, behavioural, socio-cultural, and physical environment. PA was measured by accelerometry. Outcome measures included total PA (TPA), moderate-to-vigorous PA (MVPA), SB, BMI, and skinfold thickness (SF). PA measures consisted of both PA during CC days (full day attendance) and overall PA (including all days, both home and CC days).

Results: 476 preschool children (mean age 3.9±0.7 yrs; 47% girls, 23% overweight and obese) participated in the study. Using multiple regression analysis, we identified the following CC correlates for higher TPA, higher MVPA or lower SB during CC days: older age, sex (boys), more frequent child-initiated interactions during CC, mixing different ages within a group, and the presence of a written PA convention in the CC (all $p \leq 0.02$). For higher overall TPA and/or MVPA or lower overall SB including both home and CC days correlates were: older age, sex (boys), more frequent child-initiated interactions during CC, mixing different ages within a group, parental PA involvement in the CC, and having a larger surface area in CC (all $p \leq 0.046$). Correlates for lower SF were: sex (boys), and parental PA involvement in the CC (all $p \leq 0.02$) and for lower BMI only increased age ($p=0.001$) was a correlate.

Conclusions: More frequent child-initiated interactions and mixing different ages in CC, the presence of a written PA convention and/or a larger CC surface are correlates of PA and SB during CC days, and mostly also for overall PA. Parental involvement in CC PA projects was a correlate for reduced body fat. In Switzerland, demographic/biological, psychological, and sociocultural factors are CC correlates of preschooler's PA, SB, and adiposity.

Trial registration ISRCTN: ISRCTN41045021

Registered 06 May 2014

Keywords: Childcare; Physical activity; Preschool-aged children; Adiposity; Correlates; SPLASHY.

Introduction:

The recent World Health Organisation (WHO) report about early obesity prevention measures includes the promotion of physical activity (PA) [1]. PA and sedentary behaviours (SB) are closely related to obesity and can be influenced by psychological factors [2]. Many young children spend a large portion of their week in childcare (CC) [3, 4], the CC environment can have an impact on young children's activity behaviours as well as on their motor skills and body weight [3-5]. Therefore, it is important to identify CC correlates of young children's PA, SB, and body weight [6].

Initial studies originating from the US showed that active opportunities, staff PA training and education, portable play equipment and sufficient outdoor space were positively related to children's PA behaviour [7-9]. Nevertheless, CC correlates of PA and SB might differ by country and by CC [10]. Two studies from Australia have identified less time spent indoor before going outdoor, using of indoor space for gross motor activities, lower child-staff ratios, presence of outdoor fixed equipment, and increased number of outdoor spaces with natural ground coverings as positive correlates of young children's PA [11, 12]. In European studies, other correlates such as active opportunities in CC, size of indoor area per child, and location of preschool building on the playground have been linked to PA and/or SB in preschool children [13-15]. Data from the UK showed that only one correlate, e.g. active opportunities, was associated with children's in-care PA [14]. According to the authors, correlates of the CC environment may have a more limited influence on children's PA in countries such as the UK where policies advocate child-driven play and moving freely indoors and outdoors [14].

These previous studies have focused on PA measured during CC attendance. To our knowledge, only one study examined the effect of the CC environment on children's PA levels over the entire day [16]. The authors found during one single day of observation, that 60 minutes of outdoor time or active time during CC attendance had a positive effect on the overall PA of the entire 24-hours day. This could implicate a lack of compensation by reducing PA at home or a potential carry-over effect of CC correlates on home PA. It's important to study if CC correlates also impact on overall PA and SB, thus including measurements over the whole day and all days, i.e. also days without CC attendance, as it's the overall PA behaviours are related to many important health indicators [17].

As PA and obesity are related through energy expenditure, it is important to include correlates of PA/SB and of childhood adiposity. We are aware of one study that evaluated CC correlates of adiposity [18]. The authors found that less minutes spent in SB, more time spent in active play, less offers of high fat/high sugar foods, and less opportunities for sedentary activities were associated with lower BMI or lower risk of being overweight during CC days. Although few studies investigated CC correlates of obesity, CC-based lifestyle interventions studied their influence on PA during CC as well as on obesity [5, 19, 20].

The socio-ecological model provides a useful framework for conceptualizing potential correlates of children's behaviour and health across 5 domains: demographic/biological, psychological/cognitive/emotional, behavioural, sociocultural, and physical environment [21, 22]. Such a framework will allow us to have a broader perspective on all potential correlates of PA, SB and obesity. For example, there is a lack of knowledge about CC correlates at the sociocultural level [20]. Several correlates of PA, SB and adiposity have been tested outside the CC settings, but could also be important novel correlates within the CC setting: socioeconomic status (SES) of the CC [23-25], language region of the CC [26, 27], psychological and behavioural correlates of the children while in CC such as peer relationship problems, and eating behaviour [2, 28, 29].

The aim of the current study was to investigate CC correlates of 1) PA and SB during CC days, 2) overall PA and SB including all days, both home and CC days and 3) adiposity using data of a large cross-sectional study of 2-6-year-old preschoolers. We specifically aimed to include a large range of correlates and integrate more novel correlates based on the socio-ecological model.

Methods:

Study sample and design

The Swiss Preschoolers' Health Study (SPLASHY) is a multi-site prospective cohort study including 476 preschool children aged 2 to 6 years within two sociocultural areas of Switzerland (German and French speaking part) (ISRCTN41045021). Preschool children were recruited from 84 CC within five cantons of Switzerland (Aargau, Bern, Fribourg, Vaud, Zurich), which together made up 50% of the Swiss population in 2013. Recruitment lasted from November 2013 until October 2014. The selection procedure was stratified according to one stratum with 4 levels: urban community (>100'000 inhabitants or biggest city in the canton) and rural community, each with high socioeconomic status (SES) and low SES defined according to the median maternal educational level of the community [30, 31]. For the larger urban communities, the list of CC centers was divided into high and low SES using the definition of SES according to the Swiss neighbourhood index of socioeconomic status [24]. The detailed study design and the overall objectives have been published previously [32]. The present analysis focuses on the baseline cross-sectional assessment. The study was approved by all local ethical committees (No 338/13 for the Ethical Committee of the Canton of Vaud as the main ethical committee). Parents provided written informed consent and children provided oral consent. Data collection was conducted in parallel at all study sites according to standardized procedures.

Assessment of the outcome variables

Physical activity and sedentary behaviour assessment

Children's PA and SB were objectively monitored using an accelerometer (wGT3X-BT, ActiGraph, Pensacola, Florida, USA). Children were asked to continuously wear the accelerometer around the right hip for seven consecutive days including at nights. The device was removed for water-based activities, e.g. showering or swimming. Children, parents, and CC staff received detailed instructions on the use of the activity monitor. PA data (raw data) were collected at a sampling frequency of 30 Hz, downloaded in 3-s epochs. For data analysis, periods of 20 minutes and more of consecutives zero readings were removed and considered as non-wear time. All recordings between 9pm and 7am were excluded as this most likely reflected the hours spent sleeping. Measurements with a minimum of 10 hours recordings were considered a valid day. Epoch length was set at 60-seconds to determine the level of total PA (TPA) as mean accelerometer counts per minute (cpm), moderate-to-vigorous PA (MVPA; min/day), and SB (min/day). MVPA and SB were defined as ≥2120 counts/60-s and ≤239 counts/60-s, respectively, using Butte et al. cut-offs [33], developed specifically for young children using the same accelerometer model. Data collection and processing criteria were based on a recent review [34]. Physical activity measures included PA during CC days (full day attendance) and overall PA (including all days, both home and CC days), the latter to evaluate the impact of the correlates on overall PA. For 394 (83%) children, measurements across at least 3 days (2 weekdays and 1 week-end day) were available, whereas for the remaining 82 (17%) only one valid measurement day was available. We therefore tested whether these two groups differed from each other with respect to mean values for any of the eight outcomes used in our study, but there were no significant differences (p>.05 for any of the eight outcomes, using t-tests for independent samples) and so the two groups were collapsed.

Body composition assessment

Two different adiposity measures (BMI and skinfold thickness) were assessed in the CC centre by 5 different well-trained examiners (CL, AZ, KS, AA, NM). Height was measured to the nearest 0.1 cm with a stadiometer and weight to the nearest 0.1 kg (Seca, Basel, Switzerland) using standardized procedures. BMI was then calculated as weight/height squared (kg/m^2). All measurements were taken barefoot and in light clothing. Overweight and obesity were defined based on the WHO [35] criteria. Skinfold thickness (SF) was measured using standard procedures [36] in triplicate to the nearest 0.1mm with Harpenden calipers (HSK-BI, British Indicators, UK) at the triceps, biceps, subscapular, and suprailiac crest. The sum of all four skinfolds was calculated and referred to as “skinfold thickness or body fat”.

Childcare correlates

The correlates of the CC environment (see Table 1) were mainly assessed through a modified Nutrition and Physical Activity Self-Assessment for Child Care (NAP SACC) questionnaire [37], completed by the main CC educator responsible for the group of the assessed children. In addition, in order to take into account the broader social, cultural and policy correlates that influence PA, SB and adiposity, we included additional variables to the NAP SACC items in this CC questionnaire. We refrained from including too many variables to reduce overfitting. We used the socio-ecological model of health behaviour proposed by Sallis et al. [21] to conceptualize these potential correlates. Correlates were selected and classified into 5 domains: 1) demographic/biological, 2) psychological/cognitive/emotional, 3) behavioural, 4) sociocultural, and 5) physical environment [21]. A detailed description of all 35 potential correlates is provided in Table 1. Nutritional correlates (n=15) were only used for adiposity as outcome variable.

1) Biological and demographic domain

Five variables from the biological/demographic domain were included in the analysis. Age and sex were extracted from parental report. We also included the sociocultural language region of the CC, SES and the rural-urban location of the community where the CC was located (see "Study sample and design" for more details).

2) Psychological, cognitive and emotional domain

Three variables from the psychological domain were included that assessed educators and children while in CC, as children's social and peer problems are known to be related to childhood obesity [29]. Thus, "child-initiated interaction" ("child goes toward peers") was examined using the item "good friend" of the "peer relationship problems" scale from the Strengths and Difficulties Questionnaire (SDQ) [38]. It assesses how easily the child goes towards peers. It is thus a child-initiated interaction. "Playing peers" was assessed in order to grasp the number of peers the child plays with during CC [39]. Both items were assessed by the main educators. We also investigated the support of the educators for children by rating the overall "staff support" using direct observation by the PhD and Postdocs during the testing.

3) Behavioural domain

Based on previous research, eating behaviour was chosen to assess behavioural correlates [1, 2, 29]. We used three items from the Child Eating Behaviour Questionnaire (CEBQ) to investigate the contribution of individual differences in eating behaviour (food approach and food avoidant, while in CC) to the development of obesity [40]. Item selected for the “food approach” subscale was child’s interest in food (*enjoyment of food* scale). Items selected for the “food avoidant” subscale were child eating when upset (*emotional overeating* scale), and child leaving food on the plate after meals (*satiety responsiveness* scale). The main educator responsible completed the questionnaire.

4) **Sociocultural domain**

Twenty variables from the sociocultural domain were selected. Mixing different ages within a CC group was assessed via CC questionnaire and defined as the number of age classes within a CC group. Five PA items and 13 nutritional items from the NAP SACC were considered representing the global CC policies. Parental PA involvement in the CC was also assessed, as parental involvement is a key element in obesity prevention [5, 41].

5) Physical environment domain

Six variables from the physical environmental domain were selected. CC surface was assessed and represents the ratio of the CC surface (m^2) per number of children since classroom and playground size are important characteristics in promoting PA in CC settings [7]. CC attendance of the child was based on the parental report and represents the number of full days per week children attend the CC. In addition, four PA related items from the NAP SACC questionnaire were included.

Table 1. Potential childcare correlates of physical activity, sedentary behaviour, and adiposity.

Correlates	Source	Description	Mean (SD) or %
1) Demographic-Biological			
Age	Parental report	Child's age in years	3.9 (0.7)
Sex (% male)	Parental report	Child's sex	53
Sociocultural region (% German)	Regional location of the CC	German or French speaking region of Switzerland	74
CC SES (% high)	Swiss Neighborhood index	Socioeconomic status of the community of the CC	67
CC rural/urban (% urban)	Location of the CC	Urban defined as biggest cities of each canton and cities > 100 000 inhabitants	60
2) Psychological-cognitive-emotional			
Staff support	Direct observation by research staff	Staff support for children in finding solutions to problems: scale 1-5 increasing with more support	4.2 (0.7)
Child-initiated interaction	SDQ questionnaire *Subscale: Peer relationship problems*	Child goes toward other children: Likert scale 0-4 increases with child going more toward other children	3.2 (0.8)
Playing peers	CC questionnaire	N of peers the child plays with during CC	4.5 (3.9)
3) Behavioural			
Eating behaviour			
Interest in food*	CEBQ questionnaire Subscale: Enjoyment of food	Child's interest in food: Likert scale 0-4 increases with child's interest in food	3.0 (0.8)
Eating when upset*	CEBQ questionnaire Subscale: Emotional over-eating	Child eating more when upset: Likert scale 0-4 increases with child eating more when upset	0.2 (0.4)
Leaving food on the plate*	CEBQ questionnaire Subscale: Satiety responsiveness	Child leaving food on the plate after meals: Likert scale 0-4 increases with child leaving food on plate	1.7 (0.9)
4) Socio-cultural			
Organisational policies			
Mixing different ages	CC questionnaire	N of different age classes within a CC group	4.2 (1.3)
PA policies			
Staff participation in PA	NAP SACC questionnaire Subscale: PA	Staff participation during free PA: Likert scale 0-3 increases with more	2.0 (0.7)

		staff participation	
Staff PA training	NAP SACC questionnaire Subscale: PA	N of staff members with PA training and education	0.6 (1.1)
PA convention (% yes)	NAP SACC questionnaire Subscale: PA	Presence of a written convention for promoting PA	68
Daily PA (%)	NAP SACC questionnaire Subscale: PA	Time dedicated to daily PA per CC	
		< 30 minutes	2
		31-60 minutes	25
		61-90 minutes	20
		> 90 minutes	53
Daily structured PA (min)	NAP SACC questionnaire Subscale: PA	Time in minutes dedicated to daily structured PA	30.8 (25.1)
Parental PA involvement (% yes)	CC questionnaire	Parental involvement in PA projects set up by the CC	48
Nutritional policies			
Staff nutrition training*	NAP SACC questionnaire Subscale: nutrition	N of staff members with children nutritional training and education	1.5 (0.9)
Staff food encouragement*	NAP SACC questionnaire Subscale: nutrition	Staff encouraging children to health all kind of healthy foods: Likert scale 1-4 increases with more encouragement from staff	3.8 (0.5)
Children self-service*	NAP SACC questionnaire Subscale: nutrition	Children serve themselves without any help from staff: Likert scale 1-4 increases with more food self-service from children	3.1 (0.9)
Clean plate*	NAP SACC questionnaire Subscale: nutrition	Children are encouraged to finish their plate: Likert scale 1-4 increases with more encouragement from staff to finish their plate	1.7 (1.0)
Fruits availability *	NAP SACC questionnaire Subscale: nutrition	Frequency of fruits availability in CC: scale 1-4 increases with more fruits availability	3.8 (0.4)
Vegetables availability *	NAP SACC questionnaire Subscale: nutrition	Frequency of vegetables availability in CC: scale 1-4 increases with more vegetables availability	3.4 (0.5)
Sweet drinks availability *	NAP SACC questionnaire Subscale: nutrition	Frequency of sweet drinks availability in CC: scale 0-3 increases with more sweets drinks availability	0.1 (0.4)
Juices availability *	NAP SACC questionnaire Subscale: nutrition	Frequency of juices availability in CC: scale 0-3 increases with more juices availability	0.7 (1.1)
Water availability *	NAP SACC questionnaire Subscale: nutrition	Availability of drinking water in CC: scale 0-3 increases with more water being freely available	2.9 (0.4)
Using food as reward*	NAP SACC questionnaire Subscale: nutrition	Food is used to reward desired behaviour: Likert scale 0-3	0.1 (0.3)

		increases with more food reward	
Using food as regulator*	NAP SACC questionnaire Subscale: nutrition	Food is used to control behaviour or as punishment: Likert scale 0-3 increases with more often food used to control behaviour	0.1 (0.3)
5) Physical environment			
CC surface	CC questionnaire	Ratio of the CC surface (m2) per number of children	7.0 (5.1)
CC attendance	Parental report	N of full days child attending CC per week	2.8 (1.2)
_PA_			
PA indoor space (% yes)	NAP SACC questionnaire Subscale: PA	Presence of indoor space dedicated for PA	80
PA outdoor space (% yes)	NAP SACC questionnaire Subscale: PA	Presence of outdoor space dedicated for PA	91
Fixed PA equipment	NAP SACC questionnaire Subscale: PA	N of fixed equipment related to PA	2.9 (2.5)
Mobile PA equipment	NAP SACC questionnaire Subscale: PA	N of mobile equipment related to PA	18.9 (19.8)

N= number; CC= childcare; SES= socioeconomic status; SDQ= strength and difficulties questionnaire; CEBQ= child eating behaviour questionnaire; PA= physical activity; NAP SACC= nutrition and physical activity self-assessment for child-care; *= correlates included in the models with adiposity as outcome. We used a modified version of the NAP SACC questionnaire.

Statistical analyses

In order to analyse the association between CC environment and children's PA and body composition we used regression model techniques. CC environment was assessed through the 35 above mentioned putative correlates (Table1). Children's PA outcomes were: Total PA, moderate-and-vigorous PA, SB (all 3 both during CC days and overall PA). Body composition outcomes were: BMI, and SF. These were each analysed in a separate model.

Two different regression models were applied. We first used a multiple regression model which included the entire list of putative correlates. Multiple regression models often suffer from overfitting leading to models having low predictive accuracy when predicting new samples [42]. In the present case, the problem of overfitting was exacerbated by the many missing values in the data (see below). In order to avoid overfitting we used a variable selection procedure, the least absolute shrinkage and selection operator (lasso), as a second model [43]. As previous studies are performed with the above mentioned multiple regression model, we focus on these models to enable comparisons and add the lasso results in the appendix and only refer to major concordances and discordances in the text. In the lasso model, coefficients are deliberately shrunk by implying a penalty term to the estimated sum of squares of the residuals when fitting the model [43]. Consequently, these models are somewhat more biased than those obtained from multiple regression models, but instead often exhibit strongly increased predictive accuracy. Thus, correlates whose coefficients from penalized regression have not been shrunk to zero are likely to be predictive when replicating the study under consideration. Thus, the lasso technique basically eliminates unimportant correlates from the model by setting their coefficients to zero while the relevant correlate variables remain in the model, their coefficients being usually shrunk towards zero. Note that the two coefficients for age and sex were deliberately not shrunk and thus always kept in the lasso model, as prior knowledge had demonstrated their influence on physical activity and body composition [20, 21, 44]. Predictive accuracy of both the multiple regression model and the lasso were determined by ten-fold cross validation [45]. Performance measures reported were the variance explained (R^2) and root mean square error (*RMSE*). For the lasso model, we set the tuning parameter alpha to 0.95 [46].

All outcomes and correlates were transformed if necessary to meet regression analysis assumptions (normality, homoscedasticity). For the lasso model, all variables were standardised prior to analysis. Since for the lasso no tests of significance are yet readily available, we refrain from reporting p-values [47, 48]. To run the lasso model the two R packages glmnet and caret were used [49, 50].

The data contained missing values. Overall 14% of values were missing (between 0 and 35%, depending on the variable), and 77% of all children and 84% of all variables had at least one missing value. We therefore used multiple imputation techniques to estimate missing values. To this end, prior to any analysis, missing values were repeatedly (i.e. fifty times) imputed using chained equations as implemented in the R package mice [51]. This resulted in fifty complete datasets in which missing values had been replaced by estimated values. Subsequent regression models were thus run fifty times using each of the complete datasets in turn, and results then pooled across the fifty datasets. Since to our knowledge no technique exists to date for combining lasso based results from several data files we determined the importance of each potential correlate by computing the mean and standard deviation across of lasso coefficients across all fifty data files. In addition, we counted the number of times each putative correlate was contained in the best fitting lasso model according to cross-validation (0–50). Note however, that a value near 50 does not necessarily point to a correlate with high accuracy if the best fitting lasso model had a bad fit. Thus, mean standardized lasso coefficients give a better picture of the importance of a putative correlate.

Results

The descriptive characteristics for all children are summarized in Table 2. Mean age was 3.9 ±0.7 years and 47% of the participating children were girls. Participants provided an average of 5.6 ±0.9 days of valid PA data with a mean wearing time of 12.8 hours ±0.06 per day.

Table 2. Descriptive characteristics of the participants.

Characteristics	**Total population (n=476)**
Age (years)	3.9 ±0.7
Sex	
Boys, n (%)	246 (53)
Girls, n (%)	217 (47)
Sociocultural region	
German speaking, n (%)	342 (74)
French speaking, n (%)	121 (26)
Full-day attendance at CC	2.8 (1.2)
Body composition	
Body mass index (kg/m^2)	16.02 ±1.35
Waist circumference (cm)	51.85 ±3.53
Skinfold thickness (mm)	25.93 ±5.53
Weight status*	
Overweight, n (%)	82 (18)
Obese, n (%)	24 (5)
Physical activity during CC days	
TPA (cpm)	624 ±166
MVPA (min/d)	46 ±58
SB (min/d)	357 ±65

Overall physical activity (home and CC days)	
TPA (cpm)	622 ±153
MVPA (min/d)	46 ±23
SB (min/d)	366 ±56

CC= childcare; TPA= total physical activity; LPA= light physical activity; MPA= moderate physical activity; MVPA= moderate-to-vigorous physical activity; VPA= vigorous physical activity; SB= sedentary behaviour; cpm= counts per minute; min/d= minutes per day. Physical activity during CC days denotes the physical activity and days where the child attends CC during the full day. Overall physical activity denotes physical activity during all days, i.e. home and CC days.
*Based on the WHO criteria [35].
Cut-off for the physical activity intensities are based on Butte [33].

Physical activity during childcare days (full day childcare attendance)

Multivariate associations between the 20 potential correlates across all domains and TPA, MVPA and SB during CC days are presented in Table 3a. Five variables from the biological/demographic, psychological/cognitive/emotional and sociocultural domains were identified as correlates of PA: age (older), sex (boys), child-initiated interaction with other children during CC, mixing different ages within a CC group, and the presence of a written PA convention were positively associated with TPA and MVPA during CC days (all $p \leq 0.02$). Three of 20 tested correlates from domains 2 and 4 were inversely related to SB during CC days: child-initiated interaction with other children during CC, mixing different ages within a CC group, and the presence of a written PA convention were associated with less time spent in SB (all $p \leq 0.04$). The proportion of variance explained for TPA, MVPA and SB was 19%, 22% and 17%, respectively.

Overall physical activity (during all days, i.e. home and childcare days)

Associations between potential correlates across all domains and TPA, MVPA and SB for overall PA are presented in Table 3b. Four variables from the biological/demographic, psychological/cognitive/emotional and sociocultural domains were identified as correlates of overall PA: Age (older), sex (boys), child-initiated interaction with other children during CC, and mixing different ages within a CC group were positively associated with TPA and MVPA (all $p \leq 0.045$). For MVPA, CC surface size from domain 5 was additionally identified as correlate ($p = 0.047$). Two correlates were borderline significant with increased MVPA: less staff PA training and having more mobile equipment ($p \leq 0.09$). For overall SB, two correlates from domains 1 and 2 were associated with less SB: Sex (boys), child-initiated interaction with other children during CC ($p \leq 0.04$). One correlate from domain 4 was associated with more SB: parental involvement in PA projects of the CC ($p=0.03$). Additionally, the presence of a written PA convention was borderline significant with less SB ($p \leq 0.08$). The proportion of variance explained for TPA, MVPA and SB was 20%, 27% and 14%, respectively.

Body composition

Multivariate associations between the 35 potential correlates (including nutritional variables) with BMI and skinfold thickness are presented in Table 4. For BMI, only age was inversely associated with BMI ($p=0.002$). For skinfold thickness, sex (boys) and increased parental involvement in PA projects of the CC were associated with lower skinfold thickness ($p \leq 0.02$). The proportion of variance explained for BMI and skinfold thickness was 11% and 18%, respectively.

Lasso model

Lasso regression analysis was used to test robustness (accuracy and interpretability) of our results. Details are provided in Tables S1 and S2. In summary, the standardized coefficient (SC) cut-off was, arbitrary, set at 0.07. Lasso results were very similar to the regression analysis for most of the correlates identified for TPA, MVPA, SB, BMI, and SF, corroborating the importance of these correlates mentioned in the current study. However, few discrepancies between regression and Lasso were identified: Child interaction with others in CC was associated with overall TPA and MVPA in the regression model, but was not significant in the Lasso model (SC=0.06 and 0.03, respectively). Also, parental PA involvement was associated with lower skinfold thickness in the regression model, but it was not significant in the Lasso model (SC=-0.03). On the other side, some correlates were significant in the Lasso, but not in the regression model: sex (boys), sociocultural region (German), higher SES of the CC and larger CC surface were associated with less time spent in SB during CC days (SC=0.10, -0.10, 0.07, and -0.08, respectively). Additionally, sociocultural region (German) and larger CC surface were also shown to be associated with less time spent in overall SB in the Lasso model (SC=0.13 and 0.08, respectively). Finally, age was significant for skinfold thickness in the Lasso (SC=-0.07).

Table 3. Associations of childcare correlates with physical activity and sedentary behaviour.

a) PA during childcare days (full-day attendance)

Outcomes	Correlates	β-coefficient	95% CI	P-value
Total PA (cpm)	Age	45.14	(19.35, 70.94)	**0.001**
	Sex	-52.96	(-84.65, -21.26)	**0.001**
	Child-initiated interaction*	27.68	(4.67, 50.69)	**0.02**
	Mixing ages within a CC group	26.61	(7.02, 46.21)	**0.01**
	PA convention	53.28	(12.58, 93.98)	**0.01**
Moderate-and-vigorous PA (min/d)	Age	10.09	(6.28, 13.90)	**0.001**
	Sex	-10.00	(-14.90, -5.11)	**0.001**
	Child-initiated interaction*	4.45	(1.11, 7.79)	**0.01**
	Mixing ages within a CC group	3.74	(0.80, 6.67)	**0.01**
	PA convention	7.14	(1.40, 12.88)	**0.01**
Sedentary time (min/d)	Sex	13.02	(-0.24, 26.28)	0.054
	Child-initiated interaction*	-10.01	(-19.68, -0.33)	**0.043**
	Mixing ages within a CC group	-10.35	(-18.09, -2.61)	**0.01**
	PA convention	-23.92	(-39.99, -7.86)	**0.004**

b) Overall PA (home and childcare days)

Outcomes	Correlates	β-coefficient	95% CI	P-value
Total PA (cpm)	Age	54.76	(33.23, 76.29)	**0.001**
	Sex	-58.97	(-86.64, -31.29)	**0.001**
	Child-initiated interaction*	20.81	(0.79, 40.84)	**0.04**
	Mixing ages within a CC group	18.45	(1.07, 35.84)	**0.04**
Moderate-and-vigorous PA (min/d)	Age	10.33	(7.24, 13.42)	**0.001**
	Sex	-11.39	(-15.41, -7.37)	**0.001**
	Child-initiated interaction*	3.55	(0.65, 6.46)	**0.02**
	Mixing ages within a CC group	3.25	(0.71, 5.78)	**0.01**
	Staff PA training	-2.17	(-4.72, 0.39)	0.09
	CC surface	0.51	(0.01, 1.01)	**0.047**
	Mobile equipment (per 10)	0.10	(-0.02, 0.22)	0.09
Sedentary time (min/d)	Sex	10.83	(0.24, 21.41)	**0.045**
	CC rural/urban	-13.94	(-28.67, 0.79)	0.06
	Child-initiated interaction*	-8.95	(-16.76, -1.13)	**0.03**
	Parental PA involvement	14.66	(1.61, 27.71)	**0.03**
	PA convention	-11.60	(-24.71, 1.50)	0.08

PA= physical activity; CI= confidence interval; CC= childcare; cpm= counts per minutes; min/d= minutes per day;
*5-point Likert scale
Sex defines Girls vs boys.
Child interaction indicates child's tendency to go towards other peers while in CC.
Mixing ages refers to the number of age classes in one group.
PA convention refers to having a written PA convention promoting PA participation within the CC.
Mobile equipment is expressed per 10 more equipment such as balls, frisbees, etc.
All outcome and predictor variables are unstandardized. The model always included age and sex.
Physical activity during CC days denotes the physical activity and days where the child attends CC during the full day. Overall physical activity denotes physical activity during all days, i.e. home and CC days.

Table 4. Associations of childcare correlates with body composition.

Outcomes	Correlates	β-coefficient	95% CI	P-value
BMI	Age	-0.32	(-0.53, -0.11)	**0.002**
Skinfold thickness	Sex	2.87	(1.81, 3.94)	**0.001**
	Parental PA involvement	-1.64	(-3.01, -0.28)	**0.02**

PA= physical activity; CI= confidence interval; CC= childcare; BMI= body mass index.
Sex defines Girls vs boys.

Discussion

Based on the socio-ecological model of health behaviour, this study aimed at identifying a broad range of potential CC correlates of PA, SB and adiposity in a large sample of preschool children. Those correlates tested were selected based on the following 5 domains: demographic/biological, psychological/cognitive/emotional, behavioural, sociocultural, and physical environment [21]. Besides age and sex, child-initiated interactions with other children during CC, mixing different ages within a CC group and the presence of a written PA convention were identified as correlates of preschoolers' PA and SB during CC days. Child-initiated interactions with other children during CC, mixing different ages within a CC group and the presence of a larger CC surface were also associated with higher overall PA (including all days, i.e. home and CC days) or with more time spent in overall intense PA (MVPA) levels. Parental involvement in PA projects of the CC was associated with more overall SB as well as with reduced body fat.

Physical activity during childcare days

We measured PA during CC days (full-day attendance), which is comparable to most other studies that measured PA during CC. In line with previous studies, we found that sex (boys) and age (older children) were consistent correlates of increased PA in preschool children [11, 15, 20, 52-55]. This compelling evidence suggests that gender-specific strategies could be helpful when arranging the CC environment to promote PA.

Using the socio-ecological model proposed by Sallis [21], the present study identified three previously unmeasured CC correlates of preschoolers' PA and SB. These included child-initiated interactions with other children during CC, mixing different ages within a CC group and the presence of a written PA convention. Indeed, children interacting with each other boosts child-initiated activities which have been associated with higher PA levels [9]. In line with the theory of observational learning, younger children may look up to older children and mimic their behaviours [56]. Therefore, grouping older and younger children may encourage younger children to engage more in PA behaviours if the older children show the desired behaviour. Finally, having a convention defining the objectives, means or strategies to promote PA is essential in elevating the importance of PA in a CC. Such convention can provide a conceptual framework and institutional commitment that would support participation, enjoyment and safety in PA for preschoolers [57]. Interestingly, in the current sociocultural and physical CC environments in Switzerland, generic “activities” such as promoting child interactions and mixing ages within a CC group were stronger correlates of PA and SB than more “traditional” and PA-specific correlates. Based on these results, we would generally encourage spontaneous interaction between children of different age groups, in accordance with a previous study from the UK [14].

Contrary to findings in the current study, previous studies, mostly performed in the US, have found correlates such as staff training and education, structured PA, time devoted to indoor and outdoor PA opportunities, the presence of indoor and outdoor play spaces, vegetation, location of the building in the playground, portable equipment, and outdoor fixed equipment were associated with PA during CC [7, 8, 11, 14, 15, 18, 58]. In our study, mobile equipment was borderline significant. The above-mentioned differences could be attributable to study methodologies (choice of correlates, categorization and conceptualisation of domains, choice of observation instrument used to capture CC correlates), data acquisition of PA measures, and/or different sociocultural and political environments between countries.

Overall physical activity (home and childcare days)

Previous studies looking at CC correlates focused on PA during CC. In addition to this, we were also interested in investigating the CC correlates that are related to overall PA including all days, as it is this overall PA that is important for overall health outcomes [17] and there is a lack of knowledge in this field. The current study found that child-initiated interactions with other children during CC, mixing different ages within a CC group and the presence of a larger CC surface were related to a higher overall PA and/or more time spent in overall MVPA (home and CC days). Additionally, parental involvement in PA projects of the CC was related to higher overall SB. The latter could hint toward a compensatory response behaviour outside the CC environment. To our knowledge, only one previous study investigated the effects of the CC characteristics on PA over the 24-hour day during one day of observation [16]. In contrast to our results, the authors found that time provided outdoor and total active time were associated with higher MVPA. Similarly to our data, they did not find that staff PA training, presence of indoor play space, and portable or fixed play equipment were correlates of children's MVPA. Thus, strategies in the CC promoting positive PA behaviours do not seem to lead to a complete compensation outside of the CC by reducing PA at home and might potentially even transfer outside the CC environment.

Body composition

Intervention studies showed that the CC environment has a substantial influence on obesity development in young children [18]. Thus, the obesogenic features of the CC environment should be further investigated to better tailor interventions [59-61]. We found that age (older) was associated with lower BMI. We also found that sex (boys) and parental involvement in PA projects of the CC were associated with reduced body fat. Because boys are more engaged in higher PA intensities than girls, these specific intensities can offer protection against the development of obesity. Indeed, vigorous PA is strongly associated with lower adiposity in preschoolers [62].

The importance of parental involvement to change children's lifestyle or increase motor skills has been reported in previous successful family-based [63, 64] or in CC interventions [5]. Improving fundamental movement skills in CC is successful and might lead to lower body fat [65]. On the other side, parental involvement in PA projects of the CC could just be a marker of increased overall parental commitment. In contrast to existing CC intervention studies, we only know of one study, done in the US, that looked at several CC correlates of adiposity [18]. The authors showed that less opportunities for sedentary activities, less minutes spent in SB, more time spent in active play, and less offers of high fat/high sugar foods in CC were all associated with lower BMI or lower risk of being overweight. Interestingly, they showed that 75% of the children used the computer on their observation day, while in the current study no computer was used by the children in the CCs (data not shown). Thus, large sociocultural discrepancies between countries may impact on differences in the results. The observed differences between the current study and the previous one could also be attributable to the choice in the observation instrument for the correlates and in the PA measurements (wrist watch). Nonetheless, offering children opportunities to be active and involving parents in PA projects might encourage PA participation and/or protect against adiposity.

Strengths of the current study include the conceptualisation of potential correlates of PA, SB and adiposity across 5 domains of the socio-ecological model of health behaviour, inclusion of novel correlates, multi-method approach including direct measurements, educator and parent-report information, objectively measured PA and SB both on CC days and during home and CC stay, and the relatively large study sample. Also, analyses applied of 2 statistical models, one of them novel, showed very similar results and gave a better picture on the importance of putative correlates and the robustness of our results. Limitations include the cross-sectional design which limits causation. We did not perform a direct observation of the CC environment. However, the main responsible educator of the CC group shared the information regarding the CC correlates over several weeks of observation as opposed to an observation that lasts usually one day. This might especially be important for correlates such as daily PA and time spent outside that might fluctuate between days and according to the weather and season. The high number of correlates tested might have caused random findings. However, the lasso model through the penalized regression limited irrelevant correlates to be included in the model. PA measurement during days with full-day CC attendance was not exactly time stamped to capture PA exactly during CC time only which may in turn resulted in misclassification PA during CC.

Conclusions

In conclusion, our findings provide evidence for novel CC correlates of preschoolers PA, SB, and adiposity using a socio-ecological model. CC correlates such as child-initiated interactions with other children during CC, mixing different ages within a CC group, and the presence of a written PA convention were related to children's PA during CC days and also to overall PA including all days, both home and CC days. In Switzerland, demographic/biological, psychological/cognitive/emotional and sociocultural factors were CC correlates of preschoolers' PA, SB, and adiposity. Integrating these factors might be beneficial when planning future interventions.

List of abbreviations

CC: childcare; PA: physical activity; SB: sedentary behaviour; SPLASHY: Swiss preschoolers' health study; TPA: total physical activity; MVPA: moderate-to-vigorous physical activity; BMI: body mass index; SF: skinfold thickness; WHO: world health organisation; SES: socioeconomic status; cpm: count per minute; NAP SACC; Nutrition and Physical Activity Self-Assessment for Child Care; SDQ: Strength and Difficulties Questionnaire; CEBQ: Child Eating Behaviour Questionnaire: RMSE: root mean square error; SC: standard coefficient; CI: confidence interval; min/d: minutes per day;

Declarations

Ethics approval an consent to participate

The study was approved by all local ethical committees (No 338/13 for the Ethical Committee of the Canton of Vaud as the main ethical committee). Parents provided written informed consent.

Consent for publication

Not applicable.

Availability of data and materials

The dataset supporting the conclusions of this article is available upon reasonable request to the corresponding author.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

JP: designed research of the overall study in collaboration with SM-OJ-SK; JP: designed substudy and overall analysis and structure of the manuscript; AZ-CL-ES-KS-AA-NM-TK: conducted research; AM: assisted statistical analyses; AA: wrote the paper under the supervision of JP; SM-OJ-SK: commented the paper and adapted its content; AZ-CL-KS-AA-NM-TK: contributed to data collection. All authors approved the final version of the manuscript.

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Table S1. Associations of childcare correlates with physical activity and sedentary behaviour using Lasso.

a) PA during childcare days (full-day attendance)

Outcome	Predictors	Mean-lasso coefficient	SD	Number of selection
Total PA	**Age***	**0.20**	**0.02**	**50**
	Sex*	**-0.15**	**0.02**	**50**
	Mixing ages within a CC group*	**0.13**	**0.05**	**50**
	PA convention*	**0.11**	**0.03**	**50**
	Child-initiated interaction*	**0.10**	**0.04**	**50**
	PA indoor space	0.04	0.02	47
	Parental PA involvement	-0.04	0.03	47
	Staff PA training	-0.04	0.03	46
	CC attendance	-0.04	0.03	46
	CC surface	0.04	0.03	38
	Sociocultural region	0.03	0.04	37
	Daily Structured PA	-0.03	0.03	32
	Playing peers	0.03	0.03	31
	PA outdoor space	-0.02	0.02	33
	Staff support	-0.02	0.03	29
	Daily PA	-0.02	0.03	22
	Mobile PA equipment	0.02	0.03	16
	CC SES	-0.01	0.02	29
	Fixed PA equipment	-0.01	0.02	28
	CC rural urban	0.01	0.02	28
	Staff PA participation	0.01	0.02	21
Moderate-and-vigorous PA	**Age***	**0.28**	**0.02**	**50**
	Sex*	**-0.18**	**0.02**	**50**
	Mixing ages within a CC group*	**0.11**	**0.05**	**49**
	Child-initiated interaction*	**0.10**	**0.04**	**49**
	PA convention*	**0.08**	**0.03**	**49**
	Staff PA training	-0.03	0.02	38
	PA indoor space	0.03	0.03	38
	CC surface	0.03	0.03	36
	Fixed PA equipment	-0.03	0.03	36
	Daily structured PA	-0.03	0.03	33
	Playing peers	0.03	0.04	29
	Daily PA	-0.03	0.03	28
	Mobile PA equipment	0.02	0.04	17
	Parental PA involvement	-0.01	0.02	25
	CC attendance	-0.01	0.02	25
	PA outdoor space	-0.01	0.02	22
	Staff PA participation	0.01	0.02	21
	Sociocultural region	0.01	0.01	19
	CC rural urban	0.01	0.02	19
	CC SES	0.01	0.02	15
	Staff support	0.00	0.01	11
Sedentary time	**Mixing ages within a CC group***	**-0.14**	**0.05**	**50**
	PA convention*	**-0.14**	**0.04**	**50**
	Parental PA involvement	0.10	0.03	49
	Child-initiated interaction*	**-0.09**	**0.04**	**50**
	Sex	0.09	0.02	50
	CC surface	-0.06	0.03	46
	Sociocultural region	-0.06	0.04	45
	Staff PA training	0.05	0.03	46
	CC attendance	0.05	0.04	45
	CC SES	0.04	0.03	45
	Staff support	0.04	0.04	38
	PA indoor space	-0.03	0.02	40
	CC rural urban	-0.03	0.03	38
	Daily structured PA	0.03	0.03	34
	Age	-0.02	0.02	50

	PA outdoor space	0.02	0.02	37
	Playing peers	-0.02	0.03	26
	Daily PA	0.02	0.03	22
	Mobile PA equipment	-0.01	0.02	18
	Fixed PA equipment	0.00	0.02	24
	Staff PA participation	0.00	0.01	12

PA= physical activity; SD= standard error; CC= childcare.
* Significant in the regression model
All outcomes and predictors are standardized. The model always included age and sex.

b) Overall PA (all days, both home and childcare days)

Outcome	Predictors	Mean-lasso coefficient	SD	Number of selection
Total PA	**Age***	**0.27**	**0.01**	**50**
	Sex*	**-0.18**	**0.01**	**50**
	Mixing ages within a CC group*	**0.09**	**0.03**	**50**
	CC surface	0.06	0.03	49
	Staff PA training	-0.06	0.03	49
	Child-initiated interaction *	**0.06**	**0.03**	**46**
	CC attendance	-0.05	0.04	43
	Parental PA involvement	-0.04	0.02	49
	Sociocultural region	0.02	0.02	35
	CC rural urban	0.02	0.02	34
	PA convention	0.02	0.02	32
	Staff PA participation	0.01	0.02	21
	PA indoor space	0.01	0.02	18
	Fixed PA equipment	0.00	0.01	13
	Mobile PA equipment	0.00	0.02	10
	CC SES	0.00	0.01	9
	Playing peers	0.00	0.01	8
	Staff support	0.00	0.01	6
	Daily PA	0.00	0.01	6
	PA outdoor space	0.00	0.00	6
	Daily structured PA	0.00	0.01	5
Moderate-and-vigorous PA	**Age***	**0.32**	**0.02**	**50**
	Sex*	**-0.24**	**0.01**	**50**
	Mixing ages within a CC group*	**0.12**	**0.04**	**50**
	Child-initiated interaction*	**0.09**	**0.03**	**50**
	CC surface*	**0.07**	**0.03**	**50**
	Staff PA training	-0.06	0.02	49
	CC rural urban	0.05	0.02	46
	Fixed PA equipment	-0.04	0.03	46
	CC SES	0.04	0.03	44
	Playing peers	0.04	0.03	38
	Mobile PA equipment	0.04	0.04	30
	Parental PA involvement	-0.03	0.02	43
	PA convention	0.03	0.02	43
	CC attendance	-0.03	0.03	35
	Staff PA participation	0.01	0.02	26
	Daily PA	-0.01	0.02	24
	Daily structured PA	-0.01	0.02	24
	PA outdoor space	0.00	0.01	20
	Staff support	0.00	0.01	15
	PA indoor space	0.00	0.01	16
	Sociocultural region	0.00	0.02	5
Sedentary time	Sociocultural region	-0.11	0.03	50
	Parental PA involvement*	**0.11**	**0.02**	**50**
	Sex*	**0.09**	**0.01**	**50**
	Child-initiated interaction*	**-0.09**	**0.03**	**49**
	CC surface	-0.07	0.03	48
	CC rural urban	-0.06	0.03	49
	PA convention	-0.06	0.03	48
	CC attendance	0.05	0.04	44

	Staff PA training	0.04	0.02	46
	Mixing ages within a CC group	-0.04	0.03	44
	Age	-0.02	0.01	50
	PA indoor space	-0.02	0.02	35
	Mobile PA equipment	0.01	0.01	18
	CC SES	0.00	0.00	7
	Daily PA	0.00	0.01	7
	Playing peers	0.00	0.01	11
	Staff PA participation	0.00	0.01	13
	Fixed PA equipment	0.00	0.01	9
	Staff support	0.00	0.00	5
	Daily structured PA	0.00	0.01	11
	PA outdoor space	0.00	0.00	6

PA= physical activity; SD= standard error; CC= childcare.
* Significant in the regression model.
All outcomes and predictors are standardized. The model always included age and sex.

Table S2. Associations of childcare correlates with body composition using Lasso.

Outcome	**Predictors**	**Mean-lasso coefficient**	**SD**	**Number of selection**
BMI	**Age***	**-0.15**	**0.01**	**50**
	Sociocultural region	0.03	0.02	47
	Sex	-0.02	0.01	50
	Mixing ages within a CC group	0.01	0.02	29
	Leaving food on the plate	-0.01	0.02	15
	Staff food encouragement	0.01	0.01	8
	CC surface	0.00	0.01	14
	Clean plate	0.00	0.01	10
	Daily structured PA	0.00	0.01	8
	Staff nutrition training	0.00	0.01	7
	Playing peers	0.00	0.01	6
	Using food as reward	0.00	0.01	4
	Staff support	0.00	0.00	3
	Juices availability	0.00	0.01	3
	Water availability	0.00	0.00	2
	Interest in food	0.00	0.00	2
	Sweet drinks availability	0.00	0.00	2
	Eating when upset	0.00	0.00	1
	Children self service	0.00	0.00	1
	CC attendance	0.00	0.00	1
	Vegetables availability	0.00	0.00	1
	PA convention	0.00	0.00	1
	PA indoor space	0.00	0.00	1
	Fruits availability	0.00	0.00	0
	Mobile equipment	0.00	0.00	0
	Using food as regulator	0.00	0.00	0
	CC SES	0.00	0.00	0
	CC rural urban	0.00	0.00	0
	Staff PA training	0.00	0.00	0
	PA outdoor space	0.00	0.00	0
	Child-initiated interaction	0.00	0.00	0
	Daily PA	0.00	0.00	0
	Staff PA participation	0.00	0.00	0
	Fixed PA equipment	0.00	0.00	0
	Parents PA involvement	0.00	0.00	0
Skinfold thickness	**Sex***	**0.26**	**0.01**	**50**
	Age	-0.07	0.01	50
	Staff support	-0.05	0.03	50
	CC rural urban	-0.05	0.03	48
	Parental PA involvement*	**-0.03**	**0.04**	**35**
	CC SES	0.02	0.02	32

	PA convention	0.02	0.03	26
	Staff PA training	0.02	0.03	26
	Vegetables availability	-0.01	0.02	26
	Staff nutrition training	0.01	0.01	21
	Staff PA participation	-0.01	0.02	19
	CC attendance	0.01	0.01	16
	Mobile equipment	-0.01	0.02	14
	Sociocultural region	-0.01	0.02	13
	Staff food encouragement	0.01	0.02	12
	Juices availability	-0.01	0.02	8
	Children self service	0.00	0.01	15
	PA outdoor space	0.00	0.01	12
	Child-initiated interaction	0.00	0.01	10
	Eating when upset	0.00	0.01	9
	PA indoor space	0.00	0.01	9
	Leaving food on the plate	0.00	0.01	9
	Using food as regulator	0.00	0.01	9
	CC surface	0.00	0.01	5
	Fixed PA equipment	0.00	0.01	5
	Water availability	0.00	0.01	4
	Sweet drinks availability	0.00	0.01	4
	Fruits availability	0.00	0.00	4
	Using food as reward	0.00	0.01	3
	Interest in food	0.00	0.01	3
	Clean plate	0.00	0.01	3
	Playing peers	0.00	0.00	2
	Mixing ages within a CC group	0.00	0.00	1
	Daily structured PA	0.00	0.00	1
	Daily PA	0.00	0.00	1

PA= physical activity; SD= standard error; CC= childcare.
* Significant in the regression model.
All outcomes and predictors are standardized. The model always included age and sex.

Appendix V

Publication list:

1. Messerli-Bürgy N; Kakebeeke TH; **Arhab A**; Stülb K; Zysset A; Leeger-Aschmann CS; Schmutz EA; Fares F; Meyer AH; Munsch S*; Kriemler S*; Jenni OG*; Puder JJ*. The Swiss Preschoolers' Health Study (SPLASHY): Objectives and design of a prospective multi-site cohort study assessing psychological and physiological health in young children. BMC Pediatrics. 2016, doi:10.1186/s12887-016-0617-7. (*shared last authors).

2. Leeger-Aschmann CS; Schmutz EA; Radtke T, Kakebeeke TH; Zysset AE; Messerli-Bürgy N; Stülb K; **Arhab A**, Meyer AH, Munsch S*, Jenni OG*, Puder JJ*, Kriemler S*. Regional sociocultural differences as important correlate of physical activity and sedentary behaviour in Swiss preschool children. Swiss Medical Weekly, 2016, doi:10.4414/smw.2016.14377. (*shared last authors).

3. Schmutz EA, Leeger-Aschmann CS, Radtke T, Muff, S, Kakebeeke T, Zysset A, Messerli-Bürgy N, Stülb K, Meyer A, **Arhab A**, Munsch S*, Jenni OG*, Puder JJ*, Kriemler S*. Correlates of preschool childrens' objectively measured physical activity and sedentary behaviour: a cross-sectional analysis of the SPLASHY study. International Journal of Behavioural Nutrition and Physical Activity. 2017. doi:10.1186/s12966-016-0456-9. (*shared last authors).

4. Herzig D, Eser P, Radtke T, Wenger A, Rusterholz T, Wilhelm M, Achermann P, **Arhab A**, Jenni OG, Kakebeeke T, Leegert-Aschmann C, Messerli-Bürgi N, Meyer AH, Munsch S, Puder JJ, Schmutz E, Stülb K, Zysset A, Kriemler S. Relation of heart rate and its variability during sleep with age, physical activity and body composition in young children. Frontiers Physiology 2017, doi:10.3389/fphys.2017.00109.

5. Kakebeeke TH*, Lanzi S*, Zysset AE, Amar A, Messerli-Bürgy N, Stülb K, Leeger-Aschmann CS, Schmutz EA, Meyer AH, Kriemler S#, Munsch S#, Jenni OG#, Puder JJ#. Association between body composition and motor performance in preschool children. Obesity Facts, 2017, doi:10.1159/000477406. (*shared first authors and #shared last authors)

6. Kakebeeke, T.H., Zysset, A.E., Messerli-Bürgy, N., Chaouch, A., Stülb, K., Leeger-Aschmann, C.S., Schmutz, E.A., **Arhab, A**., Rousson, V., Kriemler, S.*, Munsch, S.*, Puder, J.J.*, Jenni, O.G*. Impact of age, sex, socio-economic status and physical activity on associated movements and motor speed in preschool children. Journal of Clinical and Experimental Neuropsychology, 2017, doi:10.1080/13803395.2017.1321107. (*shared last authors).

7. Kakebeeke, T. H. *, Messerli-Bürgy*, N., Meyer, A. H., Zysset, A. E., Stülb, K., Leeger-Aschmann, C. S., Schmutz, E. A., **Arhab, A**., Puder, J. J.#, Kriemler, S.#, Munsch, S.#, Jenni, O. G.#. Contralateral Associated Movements Correlate with Inhibitory Control, and Selective and Visual Attention in Preschool Children. Perceptual and Motor Skills. 2017, doi:10.1177/0031512517719190 (*shared first authors and #shared last authors)

8. Nadine Messerli-Bürgy, Kerstin Stülb, Tanja H. Kakebeeke, **Amar Arhab**, Annina E. Zysset, Claudia S. Leeger-Aschmann, Einat A. Schmutz, Andrea H. Meyer, Ulrike Ehlert, David Garcia-Burgos, Susi Kriemler*, Oskar G. Jenni*, Jardena J. Puder*, Simone Munsch*. Emotional eating is related with temperament but not with stress biomarkers in preschool children. Appetite, 2017, doi:10.1016/j.appet.2017.08.032. (*shared last authors).