The vulnerable child in an obesogenic environment

Associations between sociodemographic and behavioural factors and weight-related anthropometric variables in Norwegian children

Hege Kristiansen

Thesis for the degree of Philosophiae Doctor (PhD)
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“Kom ikkje med heile sanningi,
kom ikkje med havet for min torste,
kom ikkje med himmelen når eg bed um ljos,
men kom med ein glimt, ei dogg, eit fjom,
slik fuglane ber med seg vassdropar frå lauget
og vinden eit korn av salt.»

Olav H. Hauge (1908-1994), På Ørnetuva, 1961

“Don’t give me the whole truth,
don’t give me the sea for my thirst,
don’t give me the sky when I ask for light,
but give me a glint, a dewy wisp, a mote
as the birds bear water-drops from their bathing
and the wind a grain of salt.”

Olav H. Hauge, translation by Robin Fulton, James Greene, Siv Hennum, 1985

CONTRIBUTORS

This thesis is based on data from the Bergen Growth Study (BGS). The BGS is a part of the Bergen Paediatric Research Group (BERG) led by Professor Pétur B. Júlíusson who is also the principal investigator of the BGS. The BERG is part of the West-Ped group, Department of Clinical Science, University of Bergen. The BGS was performed in close collaboration with Professor Robert Bjerknes, University of Bergen, and Mathieu Roelants from the Centre for Environment and Health, KU-Leuven, Belgium. The BGS was conducted almost simultaneously with The Flanders Growth Study, and with a similar modus operandi. Professor Geir Egil Eide, Centre for Clinical Research, represented a local statistical capacity in the study.

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ABBREVIATIONS

BGS	Bergen Growth Study
BMI	Body mass index
DEXA	Dual-energy X-ray absorptiometry
IOTF	International Obesity Task Force
MVPA	Moderate to vigorous physical activity
OWOB	Overweight including obesity
OR	Odds ratio
SD	Standard deviation
SES	Socioeconomic status
SSF	Subscapular skinfold
TSF	Triceps skinfold
WC	Waist circumference
WHtR	Waist-to-height ratio
WHO	World Health Organization
z-score	Standard deviation score

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ABSTRACT

Background

Childhood overweight and obesity represent important challenges. As treatment is difficult, the attention given to prevention is warranted. To identify children at risk of overweight and obesity, knowledge about the behavioural determinants is needed, but also knowledge about the psychosocial and environmental factors driving the obesity epidemic.

Aim

The overall aim of this thesis is to identify children at risk of overweight or obesity by exploring the familial, sociodemographic, and behavioural factors associated with weight status and one-year weight gain in a population of healthy Norwegian children aged 4 to 16 years.

Materials and methods

This study was based on anthropometric measurements, and sociodemographic and behavioural data collected through parental questionnaires in the Bergen Growth study (BGS). In the first paper of the study, sociodemographic and behavioural determinants and their association to overweight and obesity were examined in a cross-sectional study of 2281 children aged 6-15 years. In the second paper, sociodemographic and behavioural determinants and their association to five different anthropometric measures, Body mass index (BMI), waist circumference (WC), waist-to-height ratio (WHtR), subscapular skinfold (SSF), and triceps skinfold (TSF), were analysed in 3063 children aged 4-15. In the third paper, the association between sociodemographic and family determinants and their association to BMI z-score and BMI z-score increments after one year were studied in 769 children aged 6-15 with anthropometric data collected at baseline and also after one year.

Results

In the first paper, the prevalence of overweight and obesity was higher in children of parents with a lower education (18% vs. 12%, $p<0.001$), and they had a more obesogenic lifestyle. Children with obesity reported eating sweets less frequently than the other children. More hours of screen time was associated with overweight (OR 1.25, 1.07; 1.47) and the presence of a TV set in the child's bedroom was associated

with obesity (OR 1.81, 1.04; 3.17). A low intake of fruit and vegetables, more than 2 hours of screen-time a day, and less than 4 hours a week spent in physical activity were common risk factors in all children, independent of weight status.

In the second paper, physical activity was found to be unrelated to BMI, but associated with all the other anthropometric measures in linear regression analyses. Physical activity was associated with a lower WC (b=-0.02), WHtR (b=-0.03), SSF (b=-0.04) and TSF (b=-0.06) in girls, and a lower SSF (b=-0.07) and TSF (b=-0.07) in boys. A higher intake of vegetables was associated with a higher WC and TSF in girls. The presence of a TV set in the bedroom was associated with a higher SSF and BMI in boys before adjusting for the BMI z-score.

In the third paper, the prevalence of OWOB increased from 16.6% to 17.8% over a year ($p<0.001$). Maternal BMI was associated with higher BMI increments in their offspring (OR 1.07, 1.01; 1.13). A blended family structure was frequent in the study population (25% of children), and was associated with a higher risk of weight gain above 1 standard deviation (SD) over a year (OR 1.82, 1.16; 2.88).

Conclusion

The prevalence of overweight and obesity was higher in children of parents with a low educational level. Obesogenic behaviours were also more frequent in these children. A high screen time and the presence of a TV set in the child's bedroom were associated with overweight and obesity. Known risk factors for overweight and obesity were common in all children, independent of weight status.

Physical activity was unrelated to the BMI, but associated to skinfold thickness in both sexes, and also to WC and WHtR in girls. When studying physical activity in children, the BMI should be complemented with other anthropometric measures.

A blended family structure was common, and was associated with higher one-year BMI increments. Childhood life events can affect weight development. BMI increments could be used to monitor weight change and could be valuable in identifying children at risk of developing overweight or obesity.

1. LIST OF PUBLICATIONS

I Kristiansen H, Júlíusson PB, Eide GE, Roelants, Bjerknes R, TV viewing and obesity among Norwegian children: the importance of parental education. Acta Paediatr, 2013. Feb; **102**(2): p. 199-205. DOI 10.1111/apa.12066.

II Kristiansen H, Eide GE, Brannsether B, Roelants M, Bjerknes R, Júlíusson PB, Associations between different weight-related anthropometric traits and lifestyle factors in Norwegian children and adolescents: A case for measuring skinfolds. Am J Hum Biol, 2018. Nov; **30**(6): e23187. DOI 10.1002/ajhb.23187.

III Kristiansen, H, Roelants, Bjerknes R, Júlíusson PB, Norwegian children and adolescents in blended families are at risk of larger one- year BMI increments. Acta Paediatrica, 2019. Sept; published online. https://onlinelibrary.wiley.com/doi/full/10.1111/apa.15019

2. INTRODUCTION

The energy balance model has inspired treatment and prevention of overweight and obesity (OWOB) for years, but with limited success. When looking more closely into sociodemographic and behavioural determinants associated with childhood OWOB, other important factors emerge, both for the individual child and for the population of children. This knowledge could be important for prevention and treatment.

2.1 Background: childhood overweight and obesity

Overweight and obesity have been known from ancient times. Hippocrates (460 BC–370 BC) already described that obesity could lead to infertility and early death [1, 2], and he also described the energy balance model where food intake should be in balance with exercise [2]. Some authors have explained the increase in prevalence of overweight and obesity using an evolutionary viewpoint illustrating how the human body is not biologically adapted to our modern life [3], whereas others point to the complexity of navigating our modern societies were individual decisions must be made in an environment formed by complex structures [4].

2.1.1 Childhood overweight and obesity

A common definition of overweight and obesity is "abnormal or excessive fat accumulation that may impair health" [5]. Childhood overweight and obesity (OWOB) has now become a worldwide phenomenon [6], Figure 1 [7], and prevention is a high priority for both national public health authorities and the WHO [8]. Although children might lose weight more easily than adults, and maintain weight loss over a longer time than adults [9], prevention is always preferable. There are however considerable differences in prevalence in the different parts of the world, and also within the European region, Figure 1 [7].

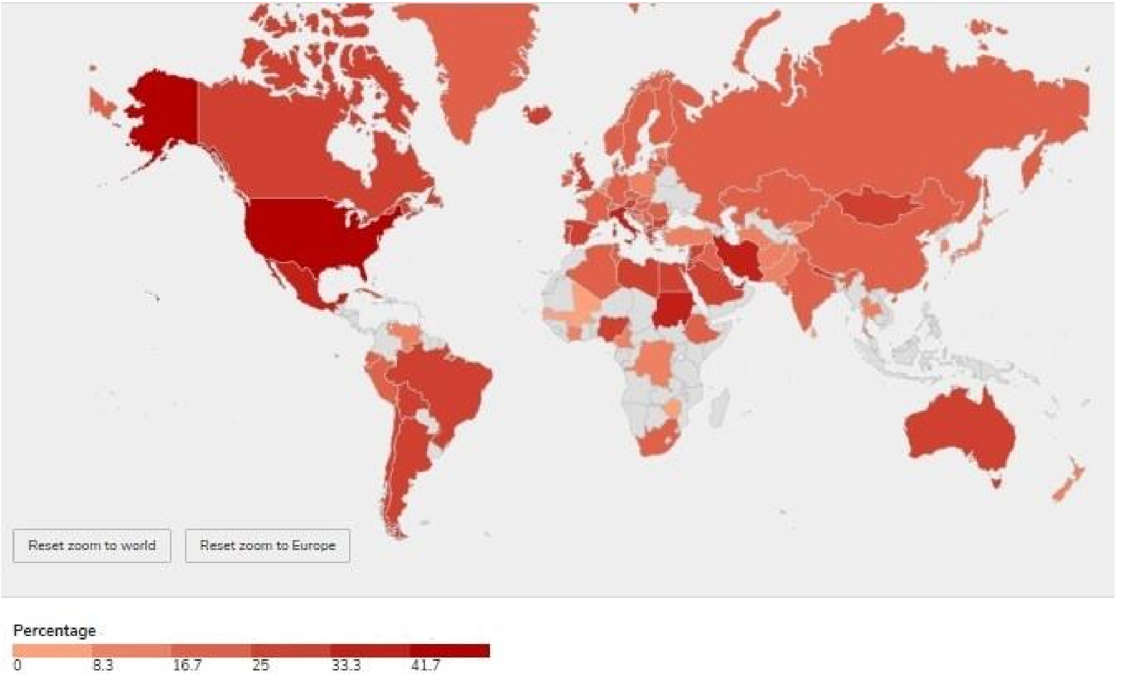

Figure 1: Prevalence of childhood obesity (WHO cut-offs), in the grey areas of the map, no data were available, Global Obesity Observatory 2018, with permission [7].

As an increasing number of children are affected, the terms obesity epidemic [10] or pandemic [11] have been put forward. The causes of the obesity epidemic are complex, ranging from individual psychological and physiological factors to social psychology and food production, as illustrated in Figure 2 [12].

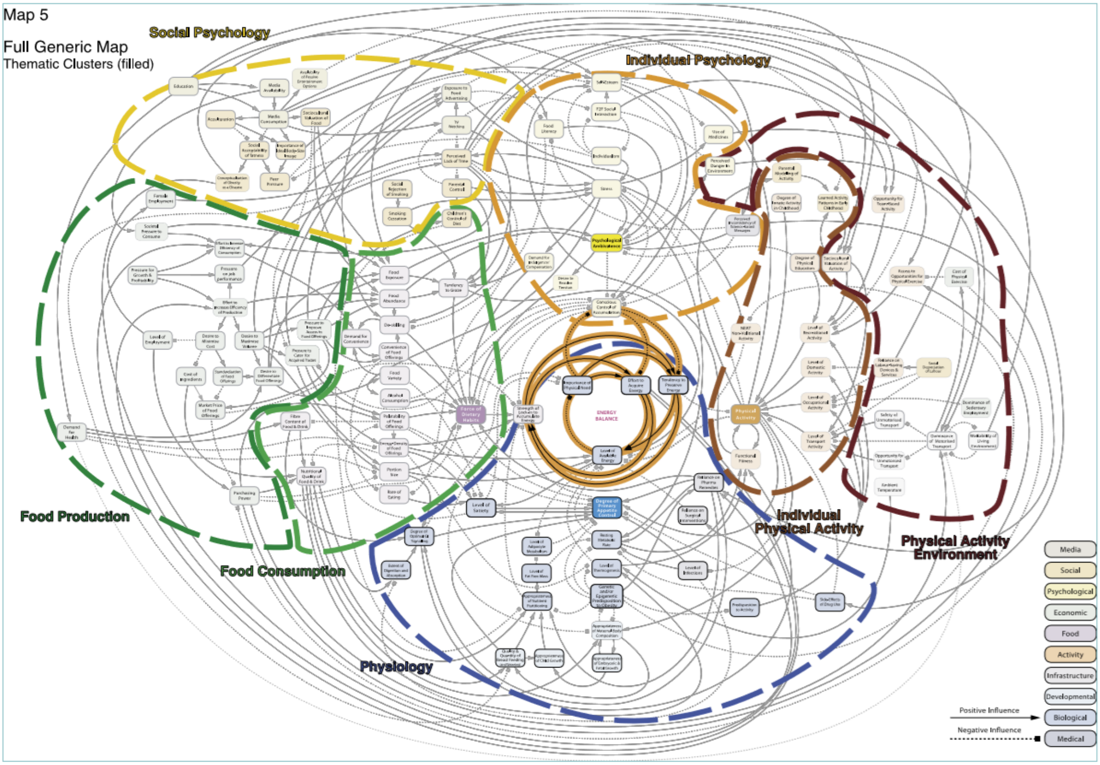

Figure 2: The full obesity system map, with thematic clusters, from Foresight (with permission [12]).

Paediatricians mainly work in the behavioural, including food consumption and physical activity, and physiological parts of this map and, to a certain degree, in the psychological parts. However, it has been claimed that the most important drivers are upstream, in the economic systems that regulate the obesogenic environments; for instance food supply and marketing and transport environment, as illustrated by Swinburn et al. in Figure 3 [11].

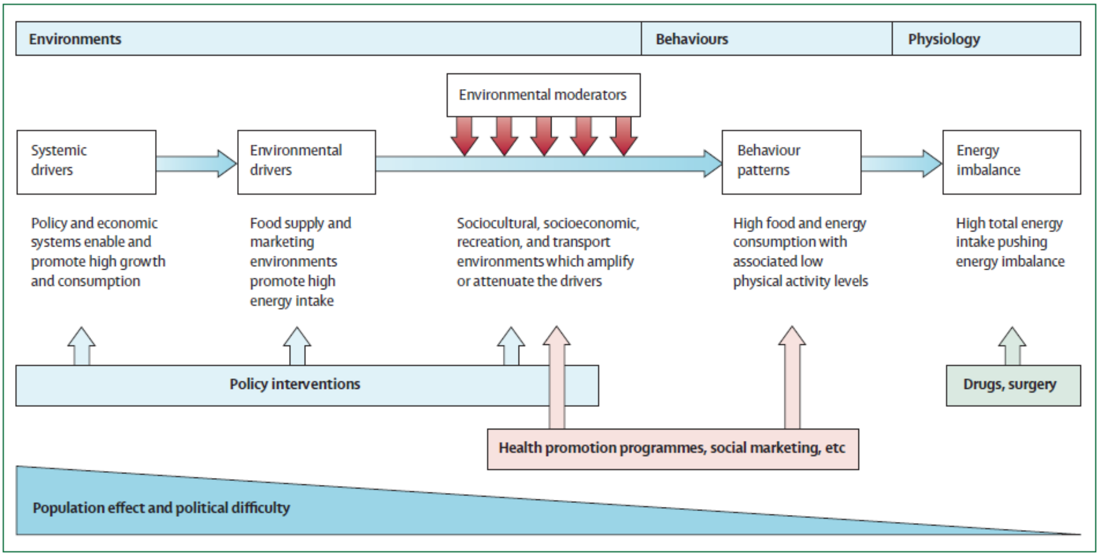

Figure 3: Framework of obesity determinants and solutions, with permission, Swinburn 2011 [11].

One of the most frequently used models of obesity is that of energy balance. By consuming more energy than they expend, the children will store this excess energy and increase in weight, or more precisely, in fat mass. For many years this has been framed as an individual problem where people "choose" to become overweight or obese, but obesity is nowadays seen as a "wicked problem" with multifactorial and interrelated causes for which there are no simple solutions [4].

2.1.2 Prevalence in Norway and the world

In 2016, the WHO estimated the worldwide number of children with OWOB to be 41 million under the age of 5 years, and another 340 million between the age of 5 and 19 years. In adults, 39% were overweight and 13% obese [5]. The Global Burden of Disease (GBD) study estimated that there were 605 million adults and 101-115 million children with obesity in the world in 2015, corresponding to an overall prevalence of obesity of 5% in children [13]. The prevalence of obesity has increased over the past 30 years, both in the USA and Europe, but with large variations [14]. Self-reported BMI has increased from 2001/02 to 2013/14 all over Europe, Figure 4 [14].

In the BGS, the overall prevalence of OWOB in Norwegian children, using the International Obesity Task Force (IOTF) cut-offs [15, 16], was estimated to be 16%, with values up to 18% in certain age groups [17]. These data are comparable to the prevalence of OWOB found in the Child Growth Study in Norway in 2015 of 16.7% in girls (3.0% obese) and 13.3% in boys (2.3% obese) for 8 year-olds [18] and to the OECD prevalence of OWOB of 12.5% for 15 years-olds in 2013-2014 in Norway, Figure 4, [14].

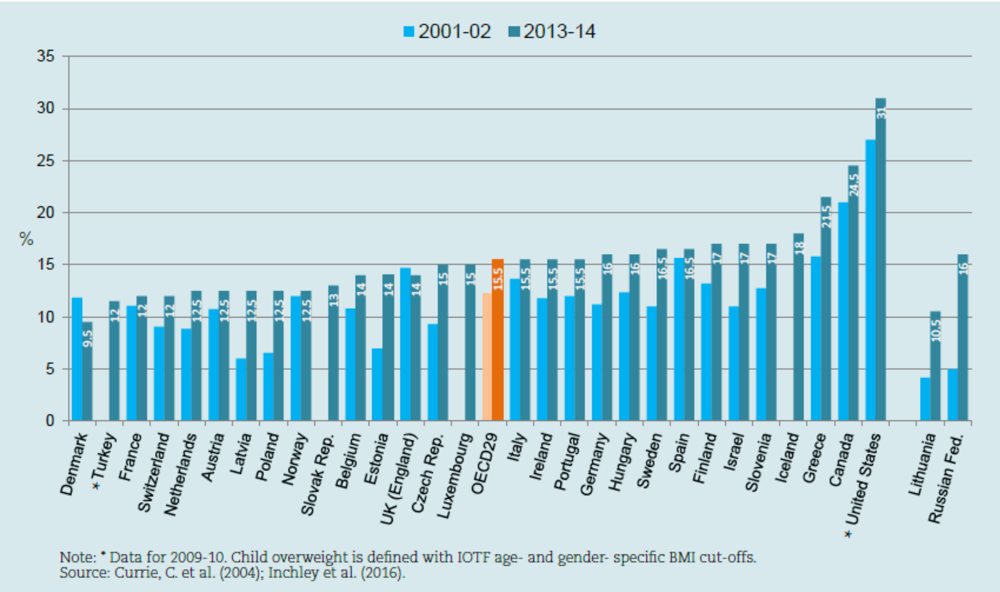

Figure 4: Self-reported prevalence of OWOB (IOTF cut-offs) at age 15 years in 2013-2014, OECD 2015 [14].

2.1.3 Consequences of overweight and obesity

The focus on childhood overweight and obesity is caused by concern for both short and long term consequences. In the GBD Study, excess body weight was found to account for about 4 million deaths and 120 million disability-adjusted life-years worldwide in 2015 [13]. Nearly 70% of the BMI-related deaths were due to cardiovascular disease, and 61% of those deaths occurred among persons with obesity, and 39% among persons with overweight.

A study with 227 000 participants, which included data from the Norwegian health surveys and from the Cause of Death Registry at the Norwegian Institute of Public Health [19], showed that adolescents with elevated BMI had a higher risk of death in middle age from endocrine, metabolic and cardiovascular disease, but also respiratory disease and cancer [20]. In a study from Aune et al., overweight and obesity were also associated with all-cause mortality in a systematic review and meta-analysis of almost 4 million deaths among more than 30 million people. The lowest risks were related to a BMI of 23-24 in never-smokers, a BMI of 22-23 in healthy never-smokers and a BMI of 20-22 with longer follow-up [21].

An increased risk for mortality in adulthood has been associated with childhood overweight and obesity, even in those who had a normal weight as adults [22, 23]. Childhood obesity has adverse effects on the cardiovascular structure and function, and also on the lifetime risk for cardiovascular disease [24]. The greatest population burden of cardiovascular disease might be in children with overweight, not among those with obesity, because the number of affected children is larger [24].

Overweight and obesity can affect many organs, as shown in Figure 5 [25], but in children and adolescents, the most important immediate consequences are often psychosocial, especially if it involves teasing or bullying [26, 27]. Musculoskeletal complaints are common and can affect ability to participate in physical activity. Steatohepatitis and hypertension are not uncommon with severe obesity in adolescence, but will only become evident upon examination.

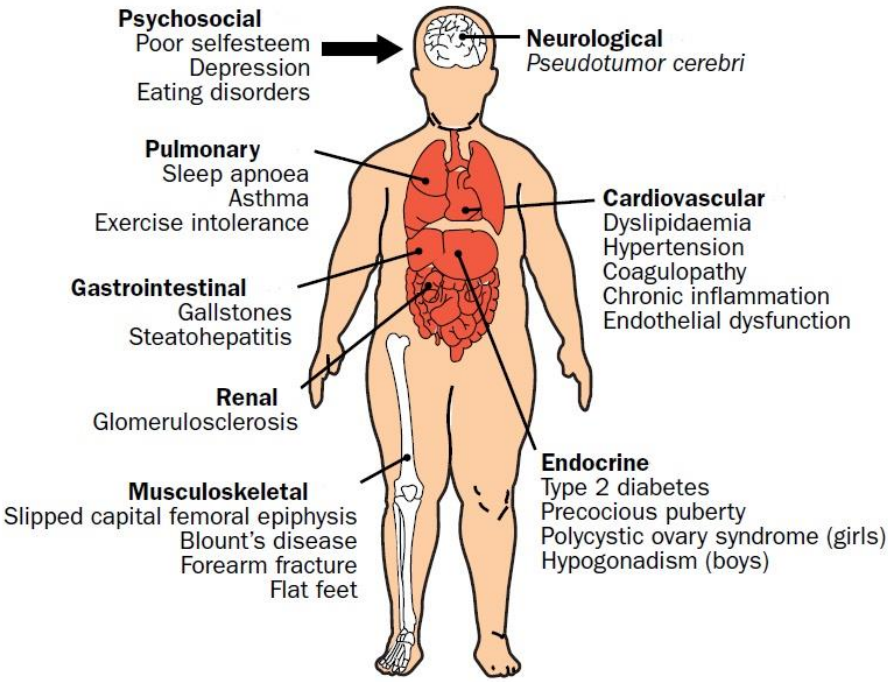

Figure 5: Complications of childhood obesity, from Ebbeling 2002, with permission [25].

2.1.4 The obesogenic environment

The obesity epidemic can be understood as a consequence of societal changes that facilitate predisposed individuals to consume more energy than they expend. The biological predisposition could involve both somatic and psychological components, including susceptibility to childhood stressors, but sociodemographic factors could also increase the risk of OWOB. The genetic predisposition has been found to involve to a large degree the CNS and responsiveness to food cues [28, 29]. Adiposity has been described as the result of a normal response, by normal people, to an abnormal situation [11]. Swinburn et al. state that the decision to consume a particular food or beverage, or to exercise or not, is without doubt an individual one, but that to negotiate the complexity of the environment and the choices it poses, many of these decisions are automatic or subconscious [11].

In complex systems, the different parts of the system interact and form relationships with the environment in non-linear ways [30]. The complex systems theory of obesity provides a framework for understanding the development of obesity as a societal problem, and offers possible pathways for a solution [4]. In a recent systematic review, Bagnall et al. found a positive effect of whole-systems approaches in overweight and obesity by improving health behaviours, leading to lower BMI, improved nutrition and increased physical activity [31].

2.1.5 Behavioural determinants

Eating habits

The eating habits of Norwegian children were not as recommended across many aspects in the years 2007-2017, as demonstrated in a study based on sales figures by the Norwegian Directorate of Health [32]. The intake of fruit and vegetables was about half the recommended rate. The intake of sweets and chocolates was high, about 15 kg per person per year, and remained largely unchanged during this period. The annual intake of sugar-sweetened beverages in Norway was also stable at about 60 litres per person, in addition to 40 litres of artificially-sweetened beverages [32]. It has been postulated that an energy balance “flipping-point” in high-income countries occurred in the 1960s-1970s, characterised by increasing energy intake [11]. This has been supported by some studies [33-35], but not all [36].

A Norwegian study, based on barcode data from food retailers [37], investigated purchases of ultra-processed food such as ready to eat/heat meals, cheese products, sweets, cakes, and sweetened drinks which accounted for 60% of purchases and 50% of money spent on food in 2013. Every third purchase was a sweet ultra-processed product, corresponding to 25% of money spent. This shows that high-caloric foods are readily available for consumption in children’s homes. As an illustration of differences between actual and recommended consumption patterns a Spanish study has redrawn the food pyramid by using bar code data of purchases, Figure 6 [38]. This corresponds also to eating habits in the Norwegian population [32].

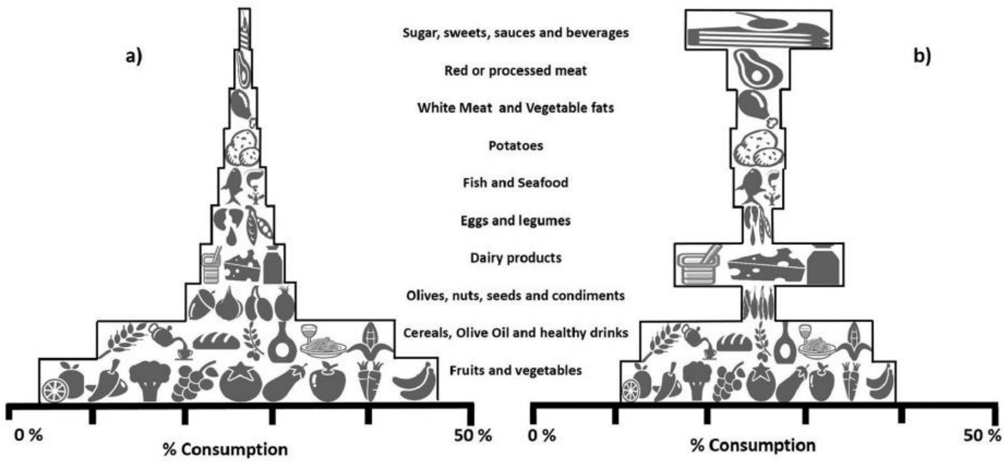

Figure 6: Food pyramids in Spain: a) estimated Mediterranean diet and b) current food consumption, with permission, Blas 2019 [38].

Unhealthy eating habits [39, 40] such as irregular meals [33, 41], high-energy food [42-45], a low intake of fruit and vegetables [46], and the frequent consumption of sugar-containing beverages [47-51] have been associated with childhood overweight and obesity. Several studies have shown that the use of BMI alone will underestimate the full effect of eating habits on adiposity [52, 53]. Skinfolds have been shown to be more strongly associated with a diet rich in fruits and vegetables than BMI [54], and more closely to a Mediterranean diet than BMI or WC in girls [55]. This indicates a need for more studies that include other anthropometric measures besides the BMI.

Screen time

Children have been found to spend a lot of their time being sedentary, and a large part of this time is spent in front of a screen, including TV viewing. According to Statistics Norway, the daily time children and adolescents spend on the internet and watching TV is about 3 hours. In 2007, about 2 hours were spent on TV viewing and 1 hour on the internet, but today this is the other way round, Figures 7 and 8 [56].

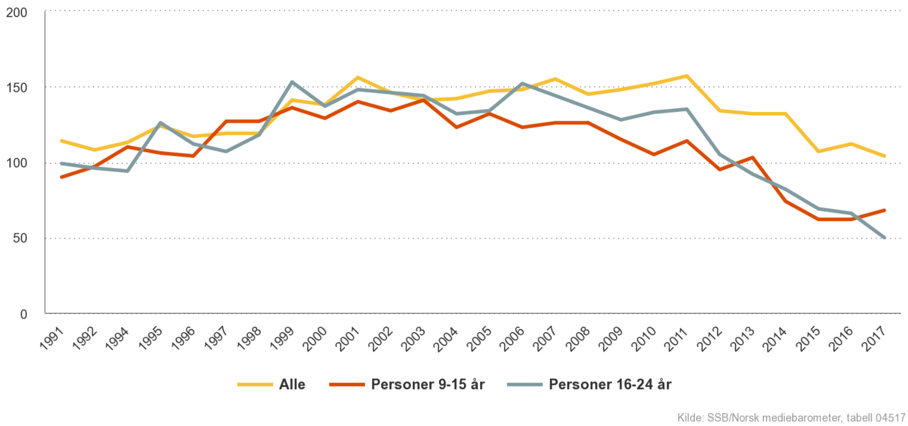

Figure 7: Minutes spent on TV viewing on an average day 1991-2017; all, 9-15 years, and 16-24 years, Statistics Norway 2007 [56].

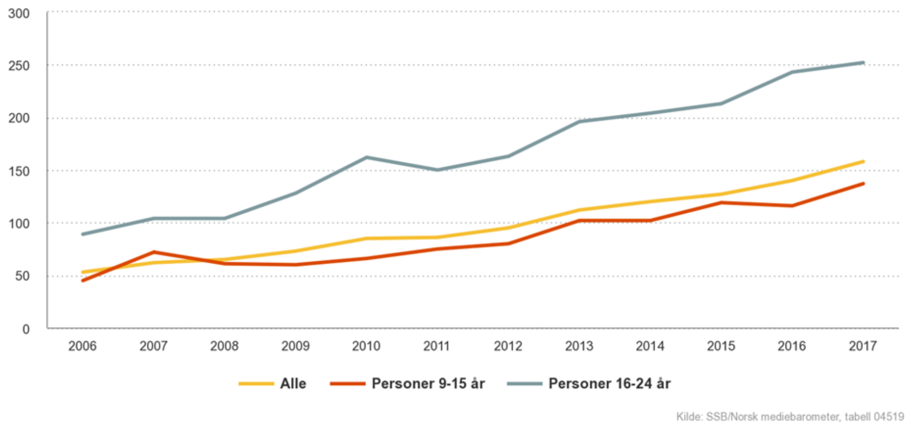

Figure 8: Minutes spent on the internet on an average day 2006-2017; all, 9-15 years, and 16-24 years, Statistics Norway 2007 [56].

In Norway, the official recommendations regarding screen time is based on guidelines from the American Academy of Paediatrics, which suggests that adolescents should not spend more than 2 hours per day in screen-based activities [57]. This recommendation is exceeded by the majority of children and adolescents today, who, according to Statistics Norway, spend on average 3.5 hours daily on screen time; 2.5 hours on the internet (half the time on gaming, half on films and videos), and about 1 hour on TV viewing [58]. Children and adolescents today have access to many electronic devices that can be used for screen time: 92% of children aged 9-12 years, and 98% of children aged 13-15 years, own a smart phone; 78% of Norwegian children aged 9-15 years have access to video games, 83% to a tablet, and 96% to a PC at home, and on average access to 2.5 TVs in their home. [58].

Screen time has been found, in several studies, to be an important risk factor for childhood overweight and obesity [59-61] although one systematic review [62] found little evidence of an association. Sedentary behaviour has been associated with a higher BMI, while the evidence is insufficient regarding WC and skinfolds [60]. The proxy measure of the presence of a TV in the child's bedroom has also been associated with childhood OWOB [61] and to fat mass [63].

Physical activity

In Norway, it is recommended that children and adolescents spend at least 60 min per day in physical activity [64]. At 9 years of age, 81% of boys and 64% of girls in Norway have been shown to spend the recommended time in physical activity, however, by 15 years of age this is down to 51% of boys and 40% of girls [64]. Many studies have identified physical activity as an important protective factor regarding OWOB in children [65-67]. Most studies used BMI as the outcome variable, although skinfolds, WC and WHtR seem to be more strongly related to adiposity in physical activity [68-73].

The use of BMI in physical activity research has some important limitations. BMI is a poor measure of body composition [74] and its accuracy varies according to body fatness: differences in BMI in relatively thin children can be due mainly to fat-free mass [72, 75], and muscular children are at risk of being misclassified as overweight [76]. There is a need for studies using anthropometric measures that are more directly related to body composition when investigating physical activity and OWOB. There are also important gender, age and sociodemographic differences regarding physical activity in children, with boys being more physically active than girls, with less physical activity in older children, and more physical activity in children with a higher socioeconomic status (SES) [77, 78].

2.1.6 Parental obesity

Parental obesity has been shown to be a strong predictor of childhood OWOB [79, 80]: children with parental obesity are more than twice as likely to have overweight or obesity [80]. Parental obesity could have an effect both through environmental factors and genetics [28].

2.1.7 Socioeconomic status

The inverse association between SES and OWOB in affluent countries is well established [81]. Historically, obesity was associated with wealth - but in high-income countries obesity is now more prevalent in persons with a low SES. In many countries in the world the "double burden" of malnutrition and obesity is present, often even in the same children, where a lack of micronutrients is present in spite of a surplus of calories [8, 11, 82]. In Scandinavian countries, the relatively small gap between the poorest and the richest has been thought to be protective in regards to childhood OWOB, but there is now a tendency towards a widening of social disparities [83, 84], which is also seen in Norway [85].

In children, SES can be assessed through parental occupation, income or education. Parental education has been shown to be a robust measure of socioeconomic position [81], and a better indicator of SES than income in the Norwegian context [86].

The relationship between SES and OWOB in children has been linked to behavioural determinants such as eating habits [78, 87], screen time [88, 89] and physical activity [77, 78, 90]. SES has also been linked to other factors associated with childhood OWOB; single parent families are more prevalent in parents with a low education (60.2%) vs high education (82.9%) [91], and both single parenthood and divorce have in turn been associated with childhood OWOB [91, 92].

2.1.8 Family factors

One of the most important functions of a family is to provide a secure environment for children to grow up and develop. The parent-child relationship plays a very powerful, formative role in establishing patterns that may, or may not, lead to healthy and adaptive health behaviours well into school age. These relationships could be affected by a change in family structure [93-97]. Family break-up and single-parent families are common childhood stressors. About half of Norwegian children will experience parental divorce before the age of 18 years [98]. In children with cohabiting parents (about half of Norwegian children), the parents split up at an even higher rate [99]. Many of these children will become members of a blended family, with the addition of a step-parent and/or step- or half-siblings.

The lifestyle habits observed at school-age are formed in early childhood and may depend on other factors besides nutrition, sedentary behaviour, activity or inactivity. Childhood stressors like family break-up could be associated with emotional eating [100-102], and physiological changes related to weight gain [103]. For these children OWOB could be seen as a symptom rather than a disease. This could be one factor explaining the limited success of interventions at school-age aimed only at behavioural determinants [104, 105], although some have showed encouraging results in younger children [106, 107]. When studying childhood OWOB, the inclusion of psychosocial factors in childhood, which could aggravate the effect of the obesogenic environment, could be useful.

2.1.9 Age and sex

Throughout the development from infant to an adult-size adolescent, there are large variations in eating habits, physical activity, mental and emotional capacity; which also differ by sex [108, 109].

Body composition also varies with age and sex, and an increase in BMI does not always reflect an increase in adiposity, particularly during puberty [110-112]. There are significant gender differences in both fat and muscle mass, which are already present in pre-pubertal children [113, 114]. After puberty, boys and men have about 20 kg more fat-free mass, mostly muscle mass, than girls and women; and women have 5-6 kg more fat mass than men [115]. There are also important sex-related differences in adipose tissue distribution before puberty, apparent even at the age of five years, as assessed by Dual-energy X-ray absorptiometry (DEXA) and Magnetic Resonance Imaging (MRI) [116].

2.2 Measuring and monitoring overweight and obesity

2.2.1 Weight-related anthropometric measures

Because children and adolescents nowadays achieve a higher mean BMI, and a higher prevalence and severity of obesity, the clinical perception of what appears normal or average will have changed [117]. Objective measures then becomes necessary to assess childhood OWOB.

Body mass index (BMI)

The BMI, measured as kg/m^2, is by far the most frequently used measure of weight status in population studies in children and adults. The BMI was first described in 1835 by Quetelet [118, 119], and the first BMI charts for children were published in 1982 by Rolland-Cachera et al. [120]. In 2000, Cole et al. established the IOTF cut-offs for overweight (IOTF25) and obesity (IOTF30) that correspond to a BMI of 25 (adult overweight cut-off) and 30 (adult obesity cut-off) kg/m^2 at the age of 18 years [15]. The full international BMI reference chart, as well as cut-offs for extreme obesity (IOTF35), were published in 2012 [16]. Both overweight and obesity, as defined by the BMI, have been linked to adult mortality, and the association is stronger with a higher degree of adiposity [13].

BMI is a global index of weight status that does not distinguish between fat mass and muscle mass, and provides no information on the distribution of body fat. Other anthropometric measures such as WC, WHtR, and skinfolds can detect excess fat in children with a normal BMI, and also identify those with an elevated BMI without obesity [74, 117, 121-123]. Despite these limitations, BMI is a frequently used measure.

Waist circumference (WC)

WC is a measure of central adiposity but can reflect both abdominal and total fat, through subcutaneous fat [122]. In adults, WC has been associated with increased mortality, including in individuals with a BMI within the normal range (BMI 20-25) [124].

WC has increased more than the BMI among children during the obesity epidemic [71, 122]. Just like the BMI, WC has been shown to be very specific, but less sensitive, in identifying excess adiposity in children [125]. WC also does not distinguish between central adiposity and muscle mass, so that males with higher muscle mass may have increased WC measurements, partially due to muscular core development [126].

There are some limitations regarding the practical use of WC. First, several different measurement methods have been described in the literature; secondly there are relatively large measurement errors in terms of both inter- and intra-observational variation; thirdly there is a need for reference curves in children, and finally WC might need some adjustment for puberty status [117]. The BGS has published national reference curves for WC in Norwegian children [127].

Waist-to-height ratio (WHtR)

WHtR has also been found to be more directly related to adiposity than BMI, and adiposity is in turn associated with metabolic risk [121, 128], also in children that are not overweight as defined by the BMI [129]. WHtR has been found to be an acceptable measure compared to DEXA [130], and is more closely associated with fat mass than BMI and WC [131]. Finally, WHtR has been linked to adult mortality [132]. In a systematic review and meta-analysis from 2016, Martin-Calvo et al. found that both WHtR and BMI could be used to identify obesity, using DEXA as a gold standard, in children aged 5-19 years in the absence of skinfolds or more advanced techniques [133].

Most commonly, a cut-off of 0.5 is used for WHtR for children above 5 years of age [130, 134]. A WHtR under 0.5 is probably a good screening index, but the cut-off of 0.5 cannot be used in children under the age of 6 years, as shown with receiver operating characteristics (ROC) analyses in the BGS [127]. In addition to this limitation, the limitations regarding WC will also apply to WHtR. Also, as WHtR is related to height, the risk of OWOB in children with height at the extremes of the distribution might not be assessed correctly by WHtR, this is also true for BMI [125].

Skinfolds

Skinfolds are direct measures of subcutaneous fat. The first skinfold charts have been attributed to Tanner in 1962 [135]. Skinfolds have been shown to be superior to BMI in identifying low body fatness, but in children with excess body fatness the two measures are equally accurate [123]. In spite of skinfolds being closely related to fat mass, there is limited data available on the relation to mortality [136, 137]. Skinfolds might not be superior to BMI in this context [138, 139], possibly because of the difficulty in measuring skinfolds correctly in individuals with severe obesity.

Skinfolds have been shown to have a stronger association with DEXA-measured fat mass than BMI or WC [131], and have also been proposed to be a better measure than Bio-electrical Impedance Analysis [125].

In Norway, updated skinfold references are available from the BGS [140], which show an increase in skinfolds between the 1970s and 2006 in children [141]. A limitation to the widespread use of skinfolds is the technical difficulty of the measurement, with a risk of large measurement errors, especially in obese individuals. The measurement of skinfolds could therefore be more useful in children with normal weight or overweight than in those with a high degree of adiposity [142].

2.2.2 BMI increments

BMI z-score increments are defined as the difference between the BMI z-score at baseline and, in annual increments, after one year. BMI increments could be used to assess the change in BMI over time. BMI increments have been shown to be a good proxy for assessing change in fat mass, compared to DEXA, in children aged 8-10 years [143].

Because the treatment of established overweight and obesity is so challenging, the identification of children increasing in weight over time could be valuable in preventing overweight. Annual BMI increments above 2 standard deviations (SD) have been shown to indicate a rapid increase in body fat in Japanese children, and corresponded to an increase of 1-2 BMI units in smaller children and 3-4 BMI units in children above 10 years [144]. An increase of 1 BMI SD in adolescence or in childhood after the age of 10 years was associated with higher body fat mass in young adulthood in a Swedish study [145]. Both a rapid increase and a greater variability in BMI in childhood were linked to adult obesity in a longitudinal study with about 20 years' observation time [146]. Identifying children with an increasing BMI z-score over time could be a way of finding those at risk of developing OWOB.

3. AIMS AND OBJECTIVES

3.1 Overall aim

The overall aim was to identify children at risk of overweight and obesity by exploring the familial, sociodemographic, and behavioural factors associated with weight status and one-year weight gain in a population of healthy Norwegian children aged 4 to 16 years.

3.2 Specific objectives and hypotheses

Paper 1. To study the association between behavioural determinants, i.e. eating habits, screen time, and physical activity with overweight and obesity in Norwegian schoolchildren. We hypothesised that unhealthy eating habits and a high amount of screen time would be associated with higher levels of overweight and obesity, and that healthy eating habits and physical activity would be associated with lower levels of overweight and obesity. We also hypothesised that parental education, our proxy measure of socioeconomic status, would be inversely related to overweight and obesity.

Paper 2. To study the association between eating habits, screen time, and physical activity with BMI, WC, WHtR, and skinfolds. We hypothesised that physical activity would be more strongly related to WC, WHtR, and skinfolds than to BMI.

Paper 3. To study if family structure was associated with one-year BMI increments. We hypothesised that children living in blended or single parent households would be more at risk of short-term weight gain, and thus of positive one-year BMI increments, than children living in a nuclear family.

4. MATERIALS AND METHODS

4.1 Study design

The main aim of the BGS was to describe the growth and weight development of Norwegian children. The study had a mixed longitudinal design, including both a cross-sectional survey and a longitudinal part.

Anthropometric data and questionnaire data on behavioural determinants and background were collected from November 2003 to December 2006, with a reminder for the questionnaire sent in January 2007. The questionnaire response rate was 67%. Follow-up measurements were performed after one year (12 ± 1 months) in children aged 7-16 years from 7 primary schools (Figure 9).

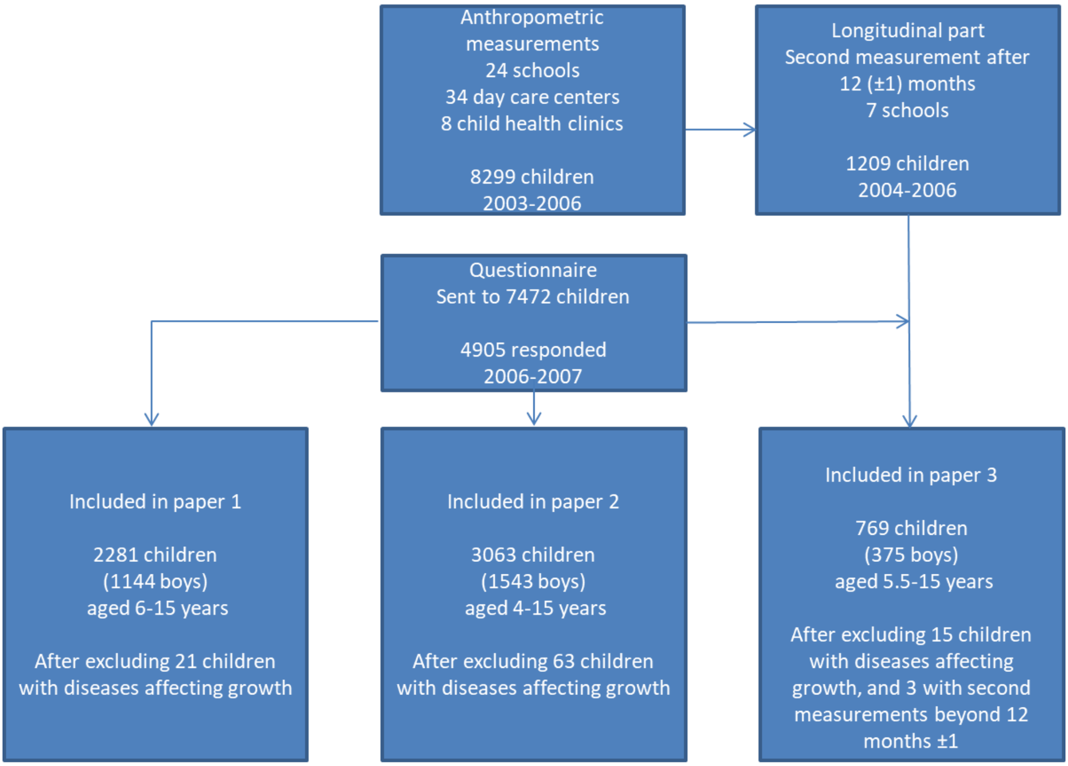

Figure 9: Overview of the study

4.2 Child population

The children were recruited from Bergen County based on a random selection of child health clinics (n=8), day care centres (n=34), and schools (n=24, including 19 primary schools or combined primary/secondary schools and 5 secondary schools), stratified by town area. A total of 8299 children aged 0-19 years were included and measured. In Bergen in 2006 there were 13 public secondary schools with 8851 pupils, of whom 1199 (13.5%) were enrolled in the study. The number of inhabitants in Bergen in 2006 was about 242 000, and about 56 000 were children under the age of 18 years [147].

About 11% of the children had parents originating from outside the Nordic countries. About 7% of the population in Bergen in 2006 were immigrants, with a majority coming from other European countries (40.8%) and the second largest group from Asia (34.8%) [148].

Children with one or both parents from outside Northern Europe (11%) and children with a chronic disease that could affect growth, for instance coeliac disease or juvenile rheumatoid arthritis, or had premature birth, were excluded (1%), leaving 7291 children (3756 boys and 3535 girls) fit for analysis and curve estimation [149].

4.3 Participation rate

In the well-baby clinics, 98% of available children were measured. Participation rate was 57% in day care centres, 69% in primary schools (1st to 7th grade), 53% in secondary schools (8th to 10th grade) and 45% in upper secondary schools (1st to 3rd year) [149].

4.4 Data collection

Public health nurses measured the participating children in the child health clinics and study nurses measured the children in day care centres and schools. The study nurses worked in teams of two, one measuring the child and the other recording the measurements. The measurements were performed during the daytime, between 08:30 and 13:00, and were directly recorded on a laptop computer. All measurements were performed by 13 trained health-care workers using a standardized technique [140, 149]. The questionnaire was distributed by mail to 7472 participants and returned by 4905 of them (67% response rate).

4.5 Anthropometric measurements

Height

From the age of two years, standing height was measured using the Harpenden Portable Stadiometer (Crosswell, UK). The children were measured in their underwear without shoes or socks. They stood with their feet together, with heels, behind and shoulders touching the meter. If the child's hair was thick, a light pressure was applied to the head plate of the meter. The head was positioned so that the lower edge of the orbita was in horizontal line with the ear opening. The measurement was performed during normal respiration and recorded to the nearest millimetre.

Weight

The weight was measured in children wearing light underwear, using a Seca personal digital scale (Hamburg, Germany), and registered to the nearest 0.1 kg.

Waist circumference

WC was measured halfway between the lower ribs and the iliac crest, wearing light underwear, at the end of a normal expiration using a steel Lufkin W606PM metal measurement tape, and recorded to the nearest millimetre.

Skinfolds

SSF was measured with a Holtain Tanner/Whitehouse Skinfold Caliper (Croswell, UK), approximately 2 cm below the inferior angle of the left scapula. TSF was measured midway between the acromion and caput radii of the posterior left overarm. Both measurements were recorded to the nearest millimetre.

Derived measures: BMI and WHtR

BMI was calculated as weight divided by height squared (kg/m^2). WHtR is a dimensionless parameter of waist circumference (in cm) divided by height (in cm).

Quality control

The stadiometers were checked at the beginning of each measuring day. The skinfold calipers were calibrated before each use. The weighing scales in the well-baby clinics were controlled twice a year and the weighing scales used in the day care centres and schools were calibrated every time they were moved to a new location.

Twice a year, all the study nurses met for a common training session. The nurses measured ten children twice, to assess measurement reliability as well as the variation between the meters.

A selection bias study was performed by questionnaire in 149 non-participating children and 368 participants. Based on these data, the prevalence of overweight and obesity was not significantly different between the groups (p=0.109) [149].

4.6 Questionnaire data

Response rate

The response rate was 62.4% for the children included in paper 1, 63.2% for those included in paper 2, and 65.5% for paper 3.

Description of items

The questionnaire included 38 items. The items concerning eating habits have been used in the studies Health Behaviour in School-aged Children (HBSC) [150, 151], Ungkost [152] and The Nord-Trøndelag Health Study in adolescents (UNG-HUNT) [153]. The items regarding physical activity have been used in Ungkost [152] and UNG-HUNT [153] and the items concerning sedentary behaviour have been used in HBSC [150, 151] and the Norwegian Mother, Father and Child Cohort Study (MoBa) [154].

Family factors

There were two items concerning the child's family. The first concerned the family where the child lived most of or all of the time (mother, father, step-mother, step-father, grandfather, grandmother) and the second about siblings and half-siblings and how many of them the child lived with.

A variable "family structure" was constructed, and children were categorized according to whether they were living in a nuclear family (with both parents), in a single parent family (no step-parent) or in a blended family (with a step-parent and/or half-siblings). There was no specific information about step-siblings in our study.

Sociodemographic factors

There were three items on the sociodemographic status. The first was about the work or study status of parents, the second about their educational level, and the third question about the origin of parents, e.g. Scandinavian, European, Asian.

Parental educational level was used as a proxy for SES because this has been shown to be a valid variable in the Norwegian population [86]. Parental educational level was classified as low (primary school, less than 12 years of education), medium (secondary school, 12 years of education) or higher education (more than 12 years of education).

Parental BMI

The BMI of parents was derived from self-reported height, and weight.

Health

Four items concerning health conditions that could affect growth; premature birth, genetic disease, long-lasting or chronic disease.

Eating habits

Two items concerned the eating habits of the child: one regarding the frequency of principal meals taken by the child (eight categories), and one regarding the frequency of consumption of fruits, vegetables, sweets, sugar-sweetened carbonated beverages and fast food (seven categories). There are four principal meals in Norway: breakfast, lunch, early dinner and an evening meal. Children taking each of the four principal meals five times or more a week were classified as having a regular meal pattern.

Screen time

Two items concerned screen time: one on daily screen time (hours of TV/DVD/PC per day in 6 categories) and the other on presence of a TV in the child's bedroom (yes/no). Children who spent more than two hours on screen activities per day were classified as having a high screen time.

Physical activity

Four items concerned physical activity: frequency of physical activity (7 categories); amount of physical activity (6 categories) and frequency of walking and cycling to school and from school, in separate questions (6 categories).

4.7 Statistical analysis

Sample size calculations

The BGS was originally designed to develop growth references, and it was estimated that 50 children per year and sex would be adequate to estimate the mean and SD, whereas a good description of the 3rd and 97th percentiles would require more children. For the growth references in the BGS, 90 to 200 children were included per sex and year, giving an adequate estimate, also at the extremes of the distribution.

For paper 1 and paper 2, based on questionnaire data in the age range of 6-15 y (paper 1) and 4-15 years (paper 2), and assuming a baseline prevalence of overweight and obesity of 13-14%, a difference in prevalence of 4% or a z-score difference of 0.1 would be statistically significant. For paper 3, when comparing equal-sized groups, a difference in prevalence of 6-7% or a z-score difference of 0.2 would be statistically significant.

Statistics

Logistic regression was used for categorical outcomes, and linear regression was used for continuous outcomes. The statistical analysis was performed with SPSS version 17 for paper 1 and IBM SPSS 24.0 (SPSS Inc., Chicago, IL, USA, 2016), for papers 2 and 3. Part of the analysis in paper 2 was carried out in R version 3.4 (R Foundation for Statistical Computing, Vienna, Austria, 2017).

Paper 1

The association between demographic characteristics and lifestyle factors with weight status (a dependent variable in 3 categories: not overweight; overweight; obese) was analysed with multinomial multiple logistic regression in SPSS 17.0. Ordinal logistic regression would have been a more attractive option (single odds ratio that describes the relationship between the three categories) but the required assumptions were not met. The association between different risk factors and weight status was expressed as an odds ratio (OR), that is the increase or decrease in odds associated with the risk factor.

In the unadjusted and the fully adjusted model, all variables were included (sex, age, parental education and all behavioural determinants), and in the step down model parental educational level was excluded to uncover behavioural determinants related to this factor, and then a backward stepwise selection was performed until only significant variables were left in the model.

Independence between parental educational level or age group and different categorical variables was tested with Pearson's chi square (e.g. high screen time and parental educational level).

Paper 2

The five anthropometric measures (WC, WHtR, SSF, TSF and BMI) were converted to z-scores (the number of standard deviations above or below the mean) adjusted for sex and age, using R version 3.4.

After checking assumptions, WC, WHtR, SSF, TSF and BMI z-scores were analysed separately as dependent variables with analysis of covariance (ANCOVA). Fully adjusted regression models included age, parental education, and all behavioural determinants and were presented for each sex separately. These models were additionally adjusted for BMI z-scores (to correct for regression to the mean and to identify the effect independently of BMI), except for the model with the BMI z-score as an outcome measure.

Results are reported as unstandardized regression coefficients (b) that express the effect on the original measurement scale of the predictor (e.g. hours of physical activity), with a 95% confidence interval.

Paper 3

Baseline BMI z-scores and BMI z-score increments were calculated in R 3.4 and SPSS 22.0.

After checking assumptions, the association between one-year increments in BMI z-score and lifestyle factors was analysed using analysis of covariance (ANCOVA) of the BMI z-score increments, adjusted for BMI z-scores at baseline. Baseline BMI z-score and maternal BMI were both entered into the models as continuous variables, and the other variables as categorical variables. In a binary logistic regression, the OR of being in the group of children with a BMI z-score increment above +1 SD was analysed. Fully adjusted regression models included baseline BMI z-score, sex, age, parental education, maternal BMI, and family structure.

Differences in BMI increments between children with normal weight or overweight, were analysed by t-tests. The prevalence of a high parental BMI in children with normal weight or overweight was analysed with a chi square test.

Results are reported as unstandardized regression coefficients (b) that express the change in outcome variable (z-score) according to changes of the predictor on the original measurement scale (e.g. unit maternal BMI) with a 95% confidence interval.

4.8 Ethics

The BGS was approved by the Norwegian Data Inspectorate (09740), and by the Regional Committee for Medical Research ethics (2010/980). One of the parents of each participating child signed an informed consent, and children above 12 years also signed.

5. SUMMARY OF RESULTS

5.1 Paper 1

In paper 1, the association between parental educational level and the children's behavioural determinants was studied in 2281 children aged 6-15 years. Parental education and behavioural factors were assessed through questionnaire data, overweight and obesity were defined by the BMI.

The prevalence of overweight and obesity was higher in children of parents with a lower educational level, as well as in those with a more obesogenic lifestyle

The overall prevalence of OWOB and obesity was 14.2% and 2.5% respectively. There were few children with overweight or obesity in the oldest age-groups. The prevalence of OWOB in children whose parents had a lower educational level was over 18%, compared to about 12% when parents had a higher educational level (chi-square $p<0.001$). Children of parents with a lower educational level had a more obesogenic lifestyle than children from parents with a higher educational level. Children from parents with a higher educational level ate fruit and vegetables more often, ate unhealthy food less often and had a more regular meal pattern. They had a TV set in their bedroom less frequently, and they performed sports more often.

Children with obesity reported eating sweets less frequently than the other children

Unhealthy eating habits such as an irregular meal pattern or a high intake of sweets were frequent in this population, including in children of parents with a higher educational level. Unhealthy eating habits were even more frequent in older children and adolescents. The obese children reported eating sweets less frequently than the healthy-weight children. This was the only eating habit associated with obesity (OR 0.58, 0.39; 0.85), but not with overweight (OR 0.89, 0.75; 1.05).

More hours of screen time and the presence of a TV set in the child's bedroom were associated with overweight and obesity

The majority of children in our study were large consumers of screen time: 80% of boys aged 12-15 years spent more than the recommended 2 hours of screen time per day. About 40% of the children had a TV in the bedroom, which was a risk factor for a high screen time. A high amount of screen time was in turn associated with a greater risk of overweight (OR 1.25, 1.07; 1.47) but not obesity (OR 1.12, 0.79; 1.60);

whereas the presence of a TV set in the bedroom was associated with obesity (OR 1.81, 1.04; 3.17), but not overweight (OR 1.26, 0.96; 1.66).

Physical activity was not related to overweight or obesity assessed by BMI

No association between physical activity and overweight or obesity was found in this study.

Both children with a healthy weight and children with overweight had many known risk factors for overweight and obesity

One out of three children ate fruit and vegetables less than 5 times a week and about half of the children ate sweets more than once a week. Half of the children and almost four out of five adolescent boys spent more than the recommended 2 hours of screen time per day. About half of the children had a TV set in their bedroom. Two out of three children performed sports less than 4 times a week and half of the children spent less than 4 hours a week in physical activity. The majority of children did not follow the recommendations regarding eating habits, screen time or physical activity.

5.2 Paper 2

In paper 2, the association between behavioural determinants and five anthropometric measures (WC, WHtR, SSF, TSF, BMI) was studied in 3063 children aged 4-15 years. Data from girls and boys were analysed separately.

Physical activity was unrelated to BMI, but associated with all the other anthropometric measures in girls, and with skinfolds in boys

The amount of physical activity was associated with a lower WC (b=-0.02), WHtR (b=-0.03), SSF (b=-0.04), and TSF (b=-0.06) in girls; and with a lower SSF (b=-0.07) and TSF in boys (b=-0.07), with a non significant trend for WHtR. In girls, there was a trend indicating that walking or cycling to school was associated with a lower WC, WHtR, and TSF; but this association disappeared after additional correction for the BMI z-score.

A higher intake of vegetables was associated with higher WC and TSF in girls

An irregular meal pattern was associated with thicker skinfolds in both boys and girls, but not after additional correction for the BMI z-score. A higher intake of sweets and sugar-sweetened beverages (SSB) was associated with lower anthropometric measures in boys, but this association disappeared when the models were adjusted for the BMI z-score. In girls, a higher intake of vegetables was associated with a higher WC (b=0.03) and thicker TSF (b=0.05), also after adjustment for BMI z-score.

Screen time was not associated with any of the anthropometric measures in boys or girls

Screen time was not related to anthropometry, but the presence of a TV set in the bedroom was associated with a higher SSF and BMI in boys, although the association with SSF was no longer significant after correction for BMI z-score.

5.3 Paper 3

In paper 3, the association between family structure (living in blended, single parent or nuclear families) and baseline BMI z-score and one-year weight change was studied in 767 children aged 6-15 years.

The prevalence of OWOB increased over a year

The prevalence of OWOB increased from 16.6% to 17.8% after a year, chi square $p<0.001$. Low parental education was associated with larger one-year BMI z-score increments.

Maternal BMI was associated with higher BMI in the children

A high maternal BMI was associated with higher baseline BMI z-scores (b=0.09), larger BMI z-score increments (b=0.01) and with larger odds of having a large (>1 SD) BMI z-score increment (OR 1.07, 1.01; 1.13). Both parents were overweight or obese in 46% of children with OWOB at baseline compared to 17% in children who were not overweight.

A blended family structure was associated with a higher weight gain over a year

One out of four children in our study lived in a blended family. In the total sample, 9% had a step-parent, 7% had both a step-parent and a half-sibling, and 16% had half-siblings but did not live with a step-parent. In total, 8% lived in a single-parent family and 66% in a nuclear family. Living in a blended family was associated with larger BMI z-score increments (b=0.06) and larger odds of having a large (>1 SD) BMI z-score increment (OR 1.82, 1.16; 2.88).

6. DISCUSSION

6.1 Introduction

Observational studies are useful for studying complex, real-life phenomena such as overweight and obesity because children cannot be randomized to different lives. Measuring all risk factors is however impossible because of the number of factors involved, both known and unknown. Because of the high number of factors involved, effect sizes in studies are usually very small. This means that it is difficult to know precisely which factors should guide treatment or policy.

In this study, familial, sociodemographic and behavioural risk factors related to childhood overweight, obesity and weight gain were identified, but these factors were also common in healthy-weight children. BMI was found to be unrelated to physical activity, in contrast to the other anthropometric measures, and it was found that BMI increments could be used to identify children at risk of overweight or obesity. The cross-sectional design of this study means that conclusions about cause and effect cannot be drawn.

6.2 Discussion of methods

Anthropometric measurements

The participation rate for the anthropometric measurements was reasonable in this study. Almost all children (98%) were included in the selected well-baby clinics (children up to the age of 6) and 57% in the day care centres. The participation rate was still at a relatively high level in primary schoolchildren (69%) but fell to 45% in upper secondary school. Non-participation in the BGS was due to illness, travel, activities in day care centres and schools, part-time attendance in day care centres, or because they declined participation. The relatively large sample size and the objectively-measured anthropometric data are some of the strengths of the BGS.

Compared to other studies in the Norwegian population during the same time period, our participation rate of 69% was acceptable. The participation rate in the studies presented in Table 1 varied from 45% [40] to 89% [155], but these studies were not quite comparable to our study because of smaller populations [156-158], a more limited age range [40, 155, 158-160], self-reported BMI [159, 161], or the lack of questionnaire data [155, 157, 159, 160].

Table 1: Comparison of BGS and other studies with prevalence data on overweight and obesity according to IOTF cut-offs in Norwegian children.

STUDY/ AUTHOR	PUBLICATION YEAR (DATA COLLECTION)	PARTICIPATION RATE (%)	NUMBER AGE IN YEARS	ANTHROPOMETRIC MEASURES	QUESTIONNAIRE	PREVALENCE (%) OF OWOB + OB	PREVALENCE IN BGS AT THE SAME AGE
BGS§ [17]	2010 (2003-06)	69%	8299 0-19	Objective	Yes		13.8%+2.3%
AHLUWALIA [159]	2015 (2002-10)	80%	5015 13-15	Self-reported	No	Boys 14% Girls 9%	10.3% 9.2%
BIEHL* [155]	2014 (2010)	89%	3166 8	Objective	No	19%	18.5%
BRUG (ENERGY) [40]	2012 (2010)	45% in Norway	7234 10-12	Objective	Yes	Boys 15.1% Girls 13.8%	Boys 16.0% Girls 14.1%
DONKOR [156]	2017 (2007)	59%	1110 5	Objective	Yes	15.7% Boys 14.1%+3.7% Girls 17.3%+4.2%	11.3% 8.6%+2.0% 13.8%+1.6%
EVENSEN [157]	2016 (2010-11)	81%	532 2-17	Objective	No	2-4 y: 11.5% 5-7 y: 13.7% 15-17 y: 20.1%	13.2% 14.7% 12.3%
HOHWÜ [161]	2014 (2011)	49% in Norway	6609 2-17	Self-reported	Yes	15.3%	13.8%
KOKKVOLL [160]	2012 (2007)	86%	1774 6	Objective	No	19%+5% Boys 16% Girls 22%	15.2%+4.4% 8.9% 21.3%
SKÅR [158]	2018 (2015)	82%	2297 6-12	Objective	Yes	14.2%+2.5-3% Boys 13.7% Girls 14.6%	16.5%+3.2% 15.5% 17.4%

§BMI in the BGS only for 2-19 years; *Child Growth Study data from Norway are included in COSI [18]

Possible selection bias was studied in children aged 7-17 years. A questionnaire was sent to 393 children that had declined to participate. Of these, 149 parents (38%)

responded and provided weight and height of their child. When comparing their BMI to that of 368 participating children, who also had answered this additional questionnaire, the prevalence of overweight and obesity was not significantly different between the groups. However, because participation in this selection bias study was also limited, the possibility of selection bias cannot be ruled out definitely, particularly in the adolescents. This will be examined further in the discussion.

All anthropometric data were objectively measured by trained study nurses and steps were taken to obtain reliable measurements by quality control of both equipment and methods. Observer reliability was assessed in test-retest studies conducted every 6 months, which included all trained observers working in that period. The inter- and intra-observer results were satisfactory [162]. As skinfold measurements are technically difficult to standardize, the use of a limited number of trained nurses was a strength of our study.

Questionnaire data

Questionnaires are an effective and feasible way of collecting data in population studies. For the questionnaire data included in our studies, a relatively good response rate (67%) was obtained, with small differences between the age groups used in the three papers. An analysis of missing data, found that few were missing from the questionnaires. In paper 1 there were <2% missing data for any one variable; in paper 2 <3% missing data for any one variable; and in paper 3 <2% missing data, except for maternal height or weight which was missing for 6.6% of cases, and paternal height or weight which was missing in 15.9% of cases. Usually if <5% of data is missing “at random”, this can be safely ignored [163]. Because variables were excluded list-wise, the analyses were only conducted on subjects with complete data. Children for whom there were no data on maternal BMI were therefore not included in the analyses in paper 3.

The questionnaire was not validated as such, but most items have been frequently used in other studies in Norway [152-154] or in international studies [150, 151].

The prevalence of OWOB according to the IOTF [15, 16] was lower in boys whose parents completed the questionnaire (11.6%) compared to those whose parents did not (15.5%) ($p=0.009$), and the boys had on average slightly lower z-scores for all anthropometric measures (range 0.06 to 0.11; all $p<0.05$), compared to the girls of the same age. In girls, there was no difference in the prevalence of OWOB between those whose parents completed the questionnaire and those who did not, but the z-scores of WHtR (-0.09) and SSF (-0.13) were slightly lower ($p<0.005$ for both) in girls for whom a questionnaire was available.

Children for whom a questionnaire was returned more often had parents with a higher educational level (62.9%) compared to census data from both the whole of Norway (26.4%), and Bergen county (33.6%) in 2007 [164]. Possible explanations are the higher educational level in cities compared to rural areas, the fact that parents belong to the younger part of the population which is more often higher educated, and finally because families with a higher educational level are more likely to participate in studies [78, 165].

The questionnaire data were collected 6 to 24 months after the anthropometric measurements. A simultaneous collection of all data would have been optimal, but was not feasible for practical reasons. Although the time gap is less problematic for variables like parental educational level, it can be a limitation when addressing behavioural determinants (e.g. causation versus selection). In paper 1 an associative study was performed and the direction of the findings cannot be assessed. Paper 2 is a comparative analysis of the association between lifestyle factors and several anthropometric measurements, and any inaccuracy rising from the time gap would apply to all anthropometric outcomes under study. The fact that the questionnaire data were collected after the anthropometric measurements could potentially have been a problem in the paper on increments (paper 3). However, the variables included in the analysis were measures that should be less susceptible to change over a year in response to weight status, compared to the behavioural determinants.

The effect of sex and age

In papers 1 and 3, sex was corrected for, and any interaction with sex was also tested. In paper 2, the analyses were stratified by sex because of large variations in body composition depending on sex in this age range. It is important to include sex as a covariable because of biological and social differences between girls and boys, bearing in mind that the variations between subjects of the same sex could be more important than the differences between the sexes.

Three age groups were chosen because of the age-related differences in growth and development, both anatomical/physiological and behavioural. The groups were: pre-pubertal (up to 8 years), transition (9-11 years) and more likely pubertal (12-16 years). Unfortunately, there were no reliable pubertal markers (besides menarche in girls) in our study, so pubertal status could not be included in the analyses, but maturity is an important factor in studies of body composition [108, 109].

Ethical considerations

The Norwegian Directorate of Health has recommended screening for weight status, and there are recommendations for follow-up of overweight and obese children. For a condition to be included in a screening program, there must be an efficient treatment that is more effective if it is introduced at an earlier time. For childhood overweight and obesity, there is only a limited effect of current interventions in the real world, especially in adolescents [104-106, 166], and this is a reason for continued research.

6.3 Discussion of results

6.3.1 Prevalence of overweight and obesity (Papers I, II, III)

The overall prevalence of overweight and obesity in the BGS varied a little between the three subpopulations included in this thesis, partly because different numbers of children were included in the three studies, and also because the age range was different in paper II. In paper I (age 6-15 years), prevalence was 14.1% for OWOB and 2.5% for obesity; in paper II (age 4-15 years), it was 11.6% and 1.6% respectively for girls, and 13.9% and 2.6% for boys; and in paper III (age 6-15 years), it was 16.6% and 4.0% respectively at baseline, and 17.8% and 2.6% after one year.

The participation rate in the BGS did not differ significantly between the different age groups. However, the response rate to the questionnaires (all papers) and participation in the follow-up measurements (paper 3) was lower in the oldest children with OWOB (Table 2). The children in the younger age groups with OWOB both returned the questionnaire and attended the second measurement at about the same rate as the children without OWOB. Others have also found that those with a higher body weight at baseline were more likely to have missing values at follow-up [78]. The prevalence of OWOB in the BGS is on the same level as other Norwegian studies (Table 1) and the sample is therefore reasonably representative.

Table 2: Participation rate in the BGS based on age groups and weight status at baseline.

Age groups	6-8 y (%) N=1207 (33.4)	9-11 y (%) N=1161 (32.2)	12-15 y (%) N=1242 (34.4)	Total N=3610 (100)
Prevalence data at baseline	1203 (99.7)	1156 (99.6)	1240 (99.8)	3599 (99.7)
Not OWOB	998 (83.0)	963 (83.3)	1104 (89.0)	3065 (85.2)
Overweight (without Obesity)	150 (12.5)	164 (14.2)	121 (9.8)	435 (12.1)
Obesity	55 (4.6)	29 (2.5)	15 (1.2)	99 (2.8)
Questionnaires sent out	1193 (98.8)	1151 (99.1)	1226 (98.7)	3570 (98.9)
Questionnaires returned	798 (66.1)	729 (62.8)	732 (58.9)	2259 (62.6)
Not OWOB	665 (83.3)	615 (84.3)	661 (90.3)	1941 (85.9)
Overweight (without Obesity)	92 (11.5)	97 (13.3)	67 (9.2)	253 (11.2)
Obesity	38 (4.8)	15 (2.1)	3 (0.4)	56 (2.5)
Registered at follow up§	**N=456 (38.3)**	**N=429 (36.0)**	**N=306 (25.7)**	**N=1191 (98.1)**
Returned questionnaire§	324 (71.1)	258 (60.1)	189 (61.7)	771 (65.0)
Not OWOB	256 (79.0)	217 (84.8)	175 (92.6)	648 (84.0)
Overweight (without Obesity)	48 (14.8)	32 (12.4)	14 (7.4)	94 (12.2)
Obesity	20 (6.2)	9 (3.5)	0 (0)	29 (3.8)

§Out of the 1209 children invited to follow-up measurements. Eighteen children were excluded because they were younger than six years.

As the prevalence of OWOB is higher in adults than in children, one would expect to find a higher prevalence as children grow older, but this was not true in the BGS and only true in the study by Evensen et al. with data on Norwegian children (Table 1) [157]. In the data from entry to the armed forces, a prevalence closer to that found in the study by Evensen et al. is reported, Figure 10 [167]. This is to some extent supported by studies like UNG-HUNT, where the prevalence in 16 year olds was about 18.5% for OWOB and 2.9% for obesity [168]. In young adults aged 20-29 years, a higher prevalence is seen, of 48.7% for OWOB and 13.3% for obesity in men and 38.6.0% and 13.6% respectively in women, but unfortunately no separate numbers are presented for the youngest adults in this study [169].

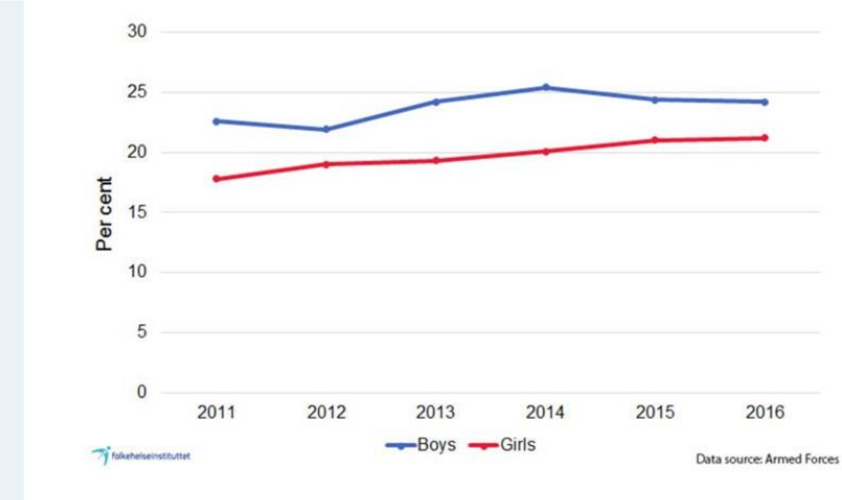

Figure 10: Self-reported OWOB at session 1 at 17 years, Armed Forces/Norhealth [167].

In a review by Cheung et al. which included 19 longitudinal studies of different study designs, incidence and remission rates in the USA were found to be highest in the youngest children [170]. There are however some important limitations in this review. There is no information about loss to follow-up, and most studies had a short follow-up period. Only 3 studies included children above 12 years [171-173], two of these included only girls [171, 173] and Kim et al. only included children up to 13 years of age in a study of one-year incidence rate [172]. The participation rate in these studies was between 56-82%. In Kim et al., an increasing prevalence up to the age of 12 years was presented, which then fell from 23% (340 children) to 20% (300 children) at age 12 years and further to 16% (100 children) at age 13 years [172]. In Thompson et al., a similar pattern is found: falling prevalence and participation rates from age 12-13 years [173]. Huh et al. also demonstrated falling prevalence from the age of 12 years: the participation rate was 56%, but there was increasing drop-out for the objectively-measured anthropometric measurements with increasing age from 4% at 14 years to 28% at age 18 years [171]. There might be a selection bias in many studies so that the adolescents with OWOB decline participation, in addition to the known variability of childhood growth that makes young children move in and out of different weight categories during the first years of childhood.

6.3.2 Parental education (Papers I, II, III)

Parental educational level was used as an indicator of SES, as it has been shown to be a better measure than employment in Norway [86]. Barriuso et al. also found that parental educational level was a better parameter than income in a systematic review of 158 papers, about 50% of which were performed in Europe [81].

Children with high parental educational levels were overrepresented in our study, as is the case in other studies [78, 165]. The majority of parents, 62.9%, had a high educational level, 30.4% had completed secondary school whereas only 6.7% had no secondary education. In our study, the prevalence of overweight and obesity was higher in children of parents with lower education. This is in agreement with other studies [81], including a study from Norway [156].

The children of lower-educated parents reported more obesogenic behaviours. They more often had unhealthy eating habits with more irregular meals and lower intake of fruits and vegetables. In another Norwegian study, meal pattern has also been found to be important [174]. In a ten year follow-up study of non-overweight adolescents from the USA, fast food was a risk factor, while protective factors were whole-grain consumption and eating breakfast and dinner in females, and vegetable consumption in males [87]. The children that had parents with less education in our study more often had a TV in their bedroom, consistent with a systematic review regarding sedentary behaviour [175]. These children also had more screen time, in agreement with other studies [89, 174]. The low SES children in the BGS less often cycled or walked to school, in agreement with Grøholt et al. [174] and they spent less time on physical activity, in agreement with Stalsberg et al. [77]. Basterfield et al., on the other hand, found SES to be unrelated to childhood overweight and obesity, but also that clustering of unhealthy or healthy behaviours could explain differences in overweight and obesity prevalence, as only 7% of the children met the recommendations for physical activity of 60 min/day and two out of three children were not eating healthily [46].

Despite the statistically significant association between SES and obesogenic behaviour, we also found that these behaviours were common in all children, regardless of parental educational level. One out of three children ate fruit and vegetables less than five times a week, in agreement with a Swedish study where they also found a low intake of fruit and vegetables [78]. About 50% of the children in our study ate sweets more than once a week, as others also have found [45, 176, 177]. About 50% watched screens for more than two hours a day, also in line with other studies [40, 178, 179] and about half of the children had a TV set in their bedroom [63]. Two out of three children in our study performed sports less than 4 times a week, in agreement with a Swedish study where 50% of children participated in sports less than 3 times a week [78]. Finally, 50% of children in the BGS spent less than 4 hours a week in physical activity, in agreement with Basterfield et al. who found that only 7% of children met the recommended 60 min/day in MVPA, as measured by accelerometers [46].

Beauchamp et al. suggested that one should aim for interventions that are shown to have an effect also in low SES children and claimed that these interventions are more structural [180]. In a systematic review Olstad et al. agree and conclude that structural interventions such as fiscal measures can reduce SES inequities in obesity and obesity-related behaviours [181]. Bammann et al. suggests that specific behaviours in the whole population should be targeted to prevent childhood OWOB and that in their study, “the association of SES and childhood overweight was fully explained by familial, psychological and behavioural factors. This result suggests that prevention measures do not inevitably have to target specific social groups” [182]. Llewellyn et al. also support this view: “targeting weight-reduction interventions specifically at obese or overweight children, although potentially useful for this sub-group of the population, is likely to have only a limited impact on reducing the overall burden of obesity-related disease in adulthood" [183].

6.3.3 Behavioural determinants (Papers I and II)

Eating habits

The children with overweight or obesity reported eating less sweets, drinking less SSB (paper 1) and eating more vegetables (paper 2) than their healthy-weight counterparts in our study. Unhealthy eating habits were common both in children with OWOB and in children with normal weight in our study. This has been confirmed in other studies [32, 38, 184] regarding snack consumption [45], meal frequency [41], and fruit and vegetable intake [185, 186].

Others have also found that children with overweight and obesity report eating fewer sweets [187], including in Norway [174, 188]. Gasser et al. performed a meta-analysis on confectionary consumption in overweight and obese children, and stated that "this result might reflect a true inverse association, reverse causality, or differential underreporting in heavier individuals" [187]. Reverse causality means that children with overweight or obesity avoid eating confectionary to avoid weight gain, whereas an inverse association would imply that children eating fewer sweets have a tendency to gain weight.

In the energy balance model, obesity is explained by the imbalance between energy input and output. In a review of reviews [189] on the causes of overweight and obesity, the authors conclude that the energy balance approach has clear limitations. Several studies have shown that estimating energy intake is very difficult in children and adolescents. In a review of the energy balance model, Hall found an error of up to 1000 kcal in a day [190], Singh et al. found that girls and boys with overweight or obesity under-estimated their energy intake by 35% [191], and Stice et al. found the same in lean adolescents [192]. Cuenca-Garcia et al. found that more physically active and leaner adolescents report higher energy intake than less active adolescents with overweight or obesity, and that this could be caused by under-reporting or higher needs [193]. In a review by Thivel et al., energy intake did not match the amount of energy expended in children, and they concluded: "Energy expenditure is not the main predictor of food consumption in both lean and obese children and adolescents" [194]. Lioret et al. found rates of under-reporting of about 5% in children aged 3-10 years and 26% in children and adolescents aged 11-17 years, without significant differences between boys and girls 2011 [195]. Skinner et al. found that young children with overweight or obesity reported consuming more calories than their healthy-weight peers, and that the inverse was true after the age of 6 years in girls and 10 years in boys [196]. Ventura et al. found that under-reporters had higher levels of weight concern [197]. In studies that include questions about weight-losing behaviour or intention, negative relations between, for instance, SSB drinking and OWOB have been reversed to positive relations in those with weight loss intention [52, 168]. Pereira et al. found in a review of 4 studies that children and adolescents have a small daily positive energy balance of 70-160 kcal that could explain weight gain over time [198].

Our finding that children with overweight and obesity reported eating more vegetables is also supported by others [185, 186, 199-201]. Rieth et al. proposed that this could be an effect of reverse causality or weight-losing behaviour [186]. The effect of reverse causality has been reported earlier, also in a Norwegian population. Fasting et al. found that the paradoxical associations between healthy dietary habits and OWOB in their study largely disappeared after adjusting for weight losing behaviour, and concluded that this was most likely an effect of reverse causality [168]. Unfortunately, there was no information about weight-losing behaviour or weight loss intention in our study.

Screen time

Screen time is the most frequently used measure of sedentary behaviour [54, 60, 89, 202, 203] but the proxy measure of the presence of a TV set in the child's bedroom has also been used [63, 71, 175, 204]. Today, the ownership of handheld screens (smart phones and tablets) would have to be added [58, 205]. There was no information in our study about the use of cell phones or smart phones which became more commonly used by adults from 2007, although not yet by children [56]. There was information about the presence of a TV set in the child's bedroom, but no information about the presence of a PC or other screens, illustrating how media use has changed in the last decade and with it the lives of children.

In our study, 56% of all children and almost 80% of adolescent boys spent more than the recommended two hours of daily screen time. A high prevalence of screen time in children, regardless of weight status, has been observed in other studies as well [56, 58, 178, 184, 206-208].

A high screen time was associated with overweight and obesity in our study; and a screen time above 2 hours daily has been associated with childhood overweight and obesity in several reviews [60, 202, 203], independent of dietary intake [54]. Biddle et al., on the other hand, found no causal relation between sedentary behaviour and adiposity in youth after applying the Bradford-Hill criteria 2017 [62].

As our study was cross sectional, the direction of the association between screen time and overweight or obesity cannot be established. In longitudinal studies, screen time has been found to be positively correlated with increased BMI [59, 209-212]. Liao et al. performed a meta-analytical, systematic review and found an effect of interventions aimed at reducing sedentary behaviour (TV, screen time, sitting time in general), but the effect size was very small [213]. According to Robinson et al., "randomized controlled trials of reducing screen time in community settings have reduced weight gain in children, demonstrating a cause and effect relationship" [205].

Current evidence suggests that one way in which screen and media exposure leads to obesity in children and adolescents is through increased eating or drinking while viewing [214]. According to Robinson et al., not only does TV watching lead to eating while being sedentary but also increases children's exposure to adverts for high-calorie, low-nutrient food and beverages [205]. There have been attempts to ban such advertising aimed at children, including in Norway, but with the internet and modern screen behaviours children are still exposed to advertising. Avery et al. found in a systematic review that children who ate while watching TV had a more unhealthy diet with a higher intake of high-fat, high-sugar foods and a lower intake of fruits and vegetables, and that this was more pronounced in low-SES families [215]. Marsh et al. found that even in the absence of food advertising, screen time was consistently found to be associated with increased dietary intake compared with non-screen behaviours [216]. This could be mediated through "distraction, interruption of physiologic food regulation, screen time as a conditioned cue to eat, disruption of memory formation, and the effects of the stress-induced reward system". Fletcher et al., on the other hand, found in a review of 21 studies that screen time was related to childhood overweight and obesity independently of food intake [54].

In our data, children with more than 2 hours of daily screen time spent less time in physical activity: 31% were active more than 4-6 times per week compared to 41% who watched screens less than 2 hours per day, and 43% spend more than 4-6 hours in physical activity per week compared to 52% of those who watched screens less than 2 hours per day. High screen time is not necessarily associated with low physical activity. In a meta-analysis by Pearson et al. there was little support for the 'displacement hypothesis', where engagement in sedentary behaviours displaces physical activity [217]. In a review by Leech et al., which observed all combinations of healthy and unhealthy behaviours in children regarding eating habits, screen time and physical activity, the authors found that healthy levels of one behaviour was not indicative of an overall healthy lifestyle [218]. Bai et al. found that screen time was a stronger factor than physical activity in predicting weight status in school-aged children [179]. A striking finding in our data was how frequent both a high screen time and low physical activity was in a normal population of Norwegian children and adolescents.

Physical activity

Physical activity is related to higher muscle mass and lower fat mass in children, but the relation to BMI is ambiguous because of the known limitation regarding body composition [74]. A child who is very physically active and has a large muscle mass and a low fat mass could have the same BMI as a physically inactive child with a low muscle mass and a large fat mass [72, 75]. Jimenez-Pavon et al. found that physical activity is negatively associated with fat mass and positively with muscle mass, independently of each other and in both genders [70]. Even before puberty there are large differences in the amount of muscle mass in children, as demonstrated by the muscle mass reference curves by McCarthy et al., Figure 11 [76].

The difficulty in distinguishing children with high BMI because of overweight from those with high muscle mass is illustrated by the following: a girl aged 5 years who measures 110 cm and weighs 19 kg (50 percentile) would shift into an overweight weight status by increasing her weight by 1.7 kg, which is less than the difference in muscle mass from the 2nd to the 98th centile for her age (3.5 kg). A boy aged 11 years who measures 147 cm and weighs 38 kg (50 percentile) would become overweight by increasing his weight by 6.5 kg, which is less than the difference in muscle mass from the 2nd to the 98th centile for his age (9.7 kg), Figure 11 [76]. In our study, there was no association between BMI and physical activity. When comparing children the same age, with the same BMI, there could be large differences in muscle mass and fat mass, also related to differences in levels of physical activity [219].

Boys	**Centile**						
	2	**9**	**25**	**50**	**75**	**91**	**98**
5.0y	3.3	3.9	4.4	5.1	5.8	6.6	7.4
6.0y	3.8	4.4	5.1	5.9	6.7	7.6	8.6
7.0y	4.4	5.1	5.9	6.7	7.7	8.7	9.8
8.0y	5.2	6.0	6.9	7.8	8.9	10.1	11.5
9.0y	6.0	7.0	8.0	9.2	10.4	11.8	13.4
10.0y	7.0	8.1	9.2	10.6	12.0	13.7	15.5
11.0y	8.1	9.3	10.7	12.2	13.9	15.7	17.8
12.0y	9.4	10.8	12.3	14.0	15.9	18.1	20.4
13.0y	10.8	12.4	14.2	16.1	18.2	20.6	23.1
14.0y	12.4	14.2	16.1	18.2	20.5	23.0	25.7
15.0y	14.1	16.0	18.1	20.3	22.7	25.2	28.0
16.0y	15.8	17.8	20.0	22.2	24.6	27.2	29.8
17.0y	17.6	19.6	21.8	24.0	26.3	28.8	31.3
18.0y	19.3	21.4	23.5	25.6	27.9	30.2	32.5

Girls	**Centile**						
	2	**9**	**25**	**50**	**75**	**91**	**98**
5.0y	3.5	4.0	4.5	5.1	5.7	6.3	7.0
6.0y	4.0	4.6	5.2	5.9	6.6	7.3	8.1
7.0y	4.7	5.3	5.9	6.7	7.5	8.4	9.3
8.0y	5.3	6.0	6.8	7.6	8.5	9.5	10.7
9.0y	6.1	6.8	7.6	8.6	9.6	10.8	12.1
10.0y	6.9	7.7	8.6	9.6	10.8	12.1	13.7
11.0y	7.9	8.8	9.7	10.9	12.1	13.6	15.3
12.0y	9.0	9.9	11.0	12.2	13.5	15.1	16.9
13.0y	10.1	11.1	12.2	13.4	14.8	16.4	18.2
14.0y	11.2	12.2	13.3	14.6	16.0	17.5	19.2
15.0y	12.3	13.3	14.4	15.6	16.9	18.4	20.0
16.0y	13.4	14.4	15.4	16.6	17.8	19.2	20.6
17.0y	14.4	15.4	16.4	17.4	18.6	19.8	21.0
18.0y	15.4	16.3	17.2	18.2	19.2	20.2	21.3

Figure 11: Skeletal muscle mass in kilos, centile values by age, with permission, McCarthy 2014 [76]

There are important differences according to gender, age and sociodemographic status regarding physical activity in children. Boys are more physically active than girls [77, 78, 108], and there is a decline in physical activity with age [77, 220, 221]. In addition, children of higher educated parents are more physically active [77, 78]. There are substantial differences between the sexes regarding muscle mass, especially after puberty, as seen in Figure 11. Boys have been found to gain 21-120% more absolute lean mass for the same amount of physical activity than girls [219].

The type of physical activity they engage in could also be different between boys and girls. Girls who walked or biked to and from school had lower WC, WHtR and TSF before correction for BMI z-score in our study. Carver et al. [222] found that active commuting could be an important source of physical activity, in particular among adolescent girls. Mendoza et al., on the other hand, found that active commuting was related to lower BMI, skinfolds and to higher MVPA in both sexes [223]. Smith et al. found that commuting was also positive regarding overall levels of physical activity [224]. One systematic review of 36 studies regarding the association between objectively-measured physical activity and adiposity in children and adolescents found that there are negative associations between walking and adiposity in cross-sectional studies, but only in 2 out of 6 longitudinal studies. Most of these studies used only BMI, which has limitation regarding body composition. The effect was found to be more pronounced in boys than in girls, but there were only a few studies that included adolescents [65]. In a fairly recent review, the role of sociodemographic differences in physical activity, overweight and obesity could not be established, possibly because of the frequent use of BMI as an outcome measure [225].

Low levels of physical activity were common both in children with normal weight and in children with OWOB in our study, and this finding has been supported by other studies [64, 178, 184, 206, 208, 226]. Physical activity has been found to be protective in regards to childhood overweight and obesity in many studies [65-67, 73, 178, 182, 218, 227], including in Norway [228]. In many of these studies, physical activity was objectively measured by accelerometer [65, 66, 178, 227, 228], in the

BGS, physical activity was parent-reported. Verstraeten et al. found that self-reported physical activity had an acceptable validity at the group level [229], whereas Colley et al. found that physical activity was associated to both lower BMI and WC, but that parents over-reported physical activity compared to accelerometers [230]. Today, children and adolescents are often wearing activity watches and fitness trackers that can provide a lot of data on activity, but this was not the case at the time of the BGS.

Many studies that used BMI found no association between BMI and physical activity, in agreement with what was observed in our study. Enes and Slater found no association between physical activity and one-year change in BMI z-score [231], and Dorsey et al. found no association with change in BMI z-score after three years [232]. Sijtsma et al. found no association between physical activity and BMI in preschool children, but did find an association with skinfolds [72].

The BMI was unrelated to physical activity in our study, whereas it was associated with skinfolds in both sexes and also to WC and WHtR in girls. Physical activity is associated with other anthropometric measures to a larger extent than the BMI. In a review by Ramires et al., studies using the BMI as the only outcome measure were excluded [73]. Physical activity has been associated with a lower WC [68-71, 233, 234], WHtR [71, 130, 134], and skinfolds [65, 69, 70, 72, 223, 233].

6.3.4 Family factors (Paper III)

Maternal BMI

Maternal BMI was used as a proxy for parental BMI variable because it has been shown to be more closely related to childhood overweight [79, 235], and because of a higher response rate for maternal than paternal BMI in our study. The prevalence of self-reported overweight and obesity in parents in our study was high: about 40% of mothers, 66% of fathers and 25% of both parents; but these rates were comparable to the population prevalence at the time [236].

Maternal BMI was associated with both BMI z-score and BMI increments in the offspring, and this could be due to both shared genetics [28] and shared environment, or the interaction of both through appetitive traits [28, 29]. In a systematic review and meta-analysis on the association between parent and child obesity, the association was stronger in older children, possibly because of longer common environmental exposures [80]. It could also be because it takes time to see the full effect of the obesogenic environment, even in the genetically and environmentally exposed [28, 80]. Children of parents with overweight or obesity have been found to be more than twice as likely to have overweight or obesity compared to children of normal-weight parents [80].

Family structure

Children who were living in a blended family increased more in weight over a year than children living in a nuclear family, where both parents were present. About half of Norwegian children will experience a divorce by their parents before the age of 18 years, and in children with cohabiting parents (about 50% of Norwegian children), the parents split up at an even higher rate [98, 99]. Family structure has been associated with childhood overweight and obesity in many studies [91, 92, 95, 237-240], including in Norwegian children [155]. In another study, including Norwegian children, this association was not found, which the authors attribute to selection bias as the response rate was low (41.5%) and possibly also because the anthropometric data were self-reported [161].

The important ACE (Adverse Childhood Events) study found a connection between childhood adverse events and adult morbidity (including obesity) and mortality [241, 242]. Obesity could in this context be understood as a symptom of difficult life-events. This association has since been confirmed in many studies, also including family break-up as a childhood adverse event [238, 240, 243, 244]. Hughes et al. points out that it is important to address the many stressors that can occur in children's lives (neglect, abuse, bullying, mental and somatic illness in relatives, to mention some), but only information about family structure was available in our study [239]. Although the association between family structure and childhood overweight and obesity is modest, the high prevalence of parental breakup and newly composed families makes the population impact high [239]. A limitation to many of these studies is the use of divorce rather than family break-up, including cohabiting parents: only a few studies have included this [91, 95]. In the Norwegian study by Biehl et al. the prevalence of divorce was low, only 7%, because they included only break-up in married parents, whereas in our study, 25% of children lived in a blended family [155].

Many studies have grouped single parent families and blended families together [95, 102, 245-247], although the life of a child living with a step-parent or a half-siblings could be very different from the life with a single parent. By using the variables step-parent and half-siblings, we were able to identify more children who experienced family break-up and who lived with a different family structure than the traditional nuclear family. But even in our study the number of children having experienced this is probably underestimated because the single parents with 50/50 custody may be included in the nuclear family category. In addition, we did not include information about the presence of step-siblings, which would presumably have added to the blended family group.

The effect of childhood stressors such as divorce or living in a blended family could be mediated through biological changes related to stress [35, 103], through emotional stress that could result in emotional eating [100-102], and through changes in behavioural determinants such as higher intake of unhealthy food [51, 92, 248, 249], more screen time [204, 249, 250], and less physical activity [250]. These behavioural determinants were not included in our analyses of BMI increments because the questionnaire data were collected after the first measurement and no data regarding the timing of the family break-up or the establishment of the blended family was available. Arkes found an increased risk of obesity two years before to six years after divorce, compared to baseline BMI a few years before divorce [240], thus attenuating the effect of the mentioned time gap limitation in our data. Hemmingsson made an interesting model of the risk factors associated with social disturbances during childhood that could also be relevant to changes in family structure, Figure 12 [251].

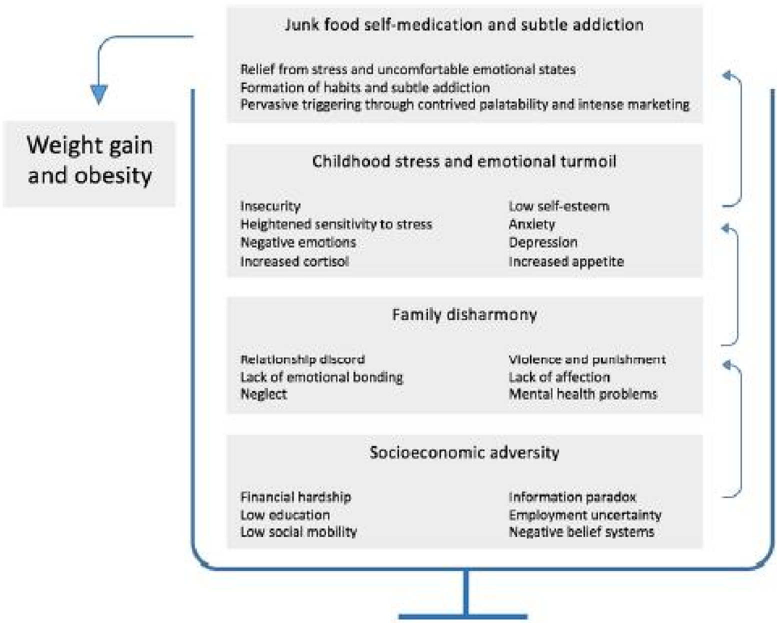

Figure 12: The overflowing-cup model of weight gain related to social disturbances in childhood, with permission, Hemmingsson 2018 [251].

6.3.5 Considerations regarding anthropometric outcome measures (Papers I, II, III)

Several outcome measures were used in this study. In paper 1, overweight, obesity and not-overweight as defined by IOTF and based on BMI were used as outcome measures. These definitions are used both in primary and specialist health care to guide interventions and are therefore interesting to study - and the use of IOTF cut-offs also makes comparisons with other studies easier [15]. An alternative could have been the use of BMI z-score, a more sensitive measure, and indeed a stronger association was found between the behavioural determinants and BMI z-score than to the IOTF cut-offs. This is because a lower intake of sugar-sweetened carbonated drinks, a higher fruit intake, irregular meals and both the presence of a TV in the child's bedroom and screen-time were associated with higher BMI z-scores, but only the latter two factors were associated with IOTF weight status.

In paper 2, BMI, WC, WHtR, SSF, and TSF, were used as outcome measures and their association with sociodemographic and behavioural determinants were compared. The association between physical activity and the 5 outcome measures was especially interesting as there was no association between physical activity and OWOB as defined by BMI in paper 1. The z-scores of all five anthropometric measures under study were used to account for differences in age and sex in this cross-sectional sample over a wide age range and to ease comparison. The correlation of the different anthropometric measures is lower in the normal to overweight range of BMI [252]. Because of biological differences in body composition between boys and girls and the fact that these differences are accentuated in puberty, the analyses were stratified by sex [110-112].

In paper 3, BMI increments were used, taken as the increase in BMI after 12 months (11-13 months). This could be a sensitive measure that could be used to identify children with an on-going unfortunate weight development, who are at risk of developing overweight and obesity [143, 146, 253]. Unfortunately, only the BMI was available from the follow-up measurements, as it would have been very interesting to look at increments in the other anthropometric measures as well. Overall there was a slight increase in BMI z-scores from baseline to one year. In the overweight or obese group, there were lower increments than in the underweight or normal weight groups. About 55% of children increased their z-score after one year, and 45% remained stable or decreased their z-score. Out of the children with increments above +1 SD, 80% were in the normal weight group at baseline. About 20%of the underweight children, 17% of the normal-weight children and 10% of the children with OWOB had BMI increments above +1 SD, as expected because of regression to the mean.

The choice of outcome measure depends on the topic under study. The most accessible alternatives to the BMI are other anthropometric measures. More technically-advanced methods, such as DEXA or MRI, are usually not available in population studies. Waist circumference has to be compared to reference curves, and for our population, national curves were developed as a part of the BGS [127]; the same applies to skinfold measurements [140]. Waist circumference has to a certain degree found its place in the clinic, whereas skinfolds are technically difficult to perform [74]. Skinfolds have therefore been used only to a limited extent both in studies and in the clinic. In our study, five different anthropometric measures were measured and compared in relation to behavioural determinants. Adding the measurement of skinfolds to the BMI for screening could potentially give additional information and help to distinguish the children with excess fat who have a normal BMI, as well as the muscular and fit children with high BMI. Anthropometric measures are highly correlated at the extremes of the weight distribution, which means that anthropometric variables other than the BMI have greater potential to add information in children who are normal weight or overweight than in obese children. This could be valuable not only in population studies but also in clinical work. When studying physical activity in childhood overweight and obesity, the use of BMI alone should be avoided because it is unrelated to body composition. If the aim is to identify children at risk of overweight or obesity, BMI increments could be a better choice than weight status based on BMI.

7 CONCLUSIONS

The association of sociodemographic and behavioural factors in Norwegian school-children with overweight and obesity, as assessed by the BMI, was studied, and the prevalence of overweight and obesity was higher in children of parents with a low educational level. A high screen time and the presence of a TV set in the child's bedroom were associated with overweight and obesity, and the presence of a TV was also associated with higher SSF and BMI in boys, before additional correction for the BMI. Screen-time does not seem to be declining in today's children and adolescents who now have screens readily at hand.

Healthy eating habits were associated with overweight and obesity. Children with overweight and obesity reported eating less sweets, and more vegetables than the other children. This could be due to under-reporting or intentional weight-loss behaviour, but no information about this was available in our study. Known risk factors related to eating habits, screen time and physical activity were common in all children, independent of weight status.

The relation of five anthropometric measures to the behavioural determinants was explored. Physical activity was found to be unrelated to BMI, but associated with skinfolds in both sexes, and also to WC and WHtR in girls. In girls, active commuting to school was also associated with lower WC, WHtR and TSF, before correction for BMI. BMI is known to be a poor measure of body composition as a physically active, muscular child might have the same BMI as a sedentary, overweight child. The use of BMI alone should be avoided in the study of physical activity in children.

A blended family structure (defined as the presence of a step-parent and/or a half-sibling) was associated with higher weight gain over a year, assessed by BMI increments. Difficult life-events can affect weight gain in children. BMI increments could be used to monitor weight change. The prevalence of overweight and obesity increased over a year in our population. An expected association between maternal BMI and both baseline BMI and BMI increments in the child was found. By also including children living in a blended-family, a larger number of children who experienced a change in family structure was identified than in other studies which used only divorce data. It is important to bear in mind that a blended family structure could also be a stressor by itself, in addition to the preceding experience of a family break-up. The association with overweight and obesity could be mediated by physiological stress, emotional eating or changes in behavioural determinants in the new families.

8 PERSPECTIVES

8.1 Research implications

1. There is a need for studies that include more adolescents to obtain better estimates of the prevalence of overweight and obesity between 12 and 18 years.
2. Studies on psychosocial factors as well as behavioural determinants could be valuable, and particularly studies regarding their interaction in the children with, or at risk for, overweight or obesity. Intervention studies could be valuable in at-risk populations, preferably before the onset of OWOB.
3. Studies, regarding the long term effect of an obesogenic environment on children with normal weight could be interesting.
4. Studies regarding blended families should include data on non-married couples, the timing of family-break-up and of the formation of the blended family, and more information about psychological and behavioural determinants.
5. When studying physical activity, the use of BMI as the only outcome measure should be avoided, because of the limitations regarding body composition.

8.2 Health promotion implications

1. BMI increments could be used to monitor weight change, and repeated measurements could be valuable to identify children at risk for OWOB who could benefit from an intervention.
2. The obesogenic environment is promoting obesity in children, but we must be equally interested in normal-weight children because many future adults with overweight and obesity come from this group. Emotional, sociodemographic and behavioural risk factors are also present in this group and could even be more interesting in a preventive context. Targeting behaviours instead of weight status might also reduce stigma.
3. We must build a society that supports vulnerable families, and offer multidisciplinary help to those most at risk of developing adverse health consequences, including obesity. A closer cooperation between somatic and psychiatric health services might benefit these children both in terms of prevention and treatment.

4. In clinical practice, talking about the complexity of obesity could be a way of reducing stigma and promoting trust and cooperation. The complex systems theory could also reduce frustration in the care-providers and act as a motivator.

8.3 Policy implications

1. Some of the differences in prevalence of childhood overweight and obesity between countries have been attributed to differences in social welfare; and in a global perspective, the Nordic countries have a strong tradition of providing a secure environment aimed at better health. A strong focus on the family by providing economic security through parental leave, free access to preventive health services as well as family physicians and hospitals are only some of the factors that could prevent childhood adversities and hence prevent among others childhood overweight and obesity. Maintaining these structures will be important in the future, but there is a need for more resources in some domains, like child protection services and psychiatric specialist wards for children and adolescents in Norway.
2. Changing our obesogenic environment is difficult because of its complexity. Policies aimed at protecting children from unhealthy behaviours, by reducing access to unhealthy foods, limiting screen time, and promoting physical activity, is not always an easy choice for our politicians [254]. To conclude, in the words of Sabin et al.: "Is it time to accept that targeting surface behaviours is unlikely to reduce childhood obesity either for individuals or society?" [255].

9 REFERENCES

1. Komaroff, M., *For Researchers on Obesity: Historical Review of Extra Body Weight Definitions.* J Obes, 2016. **2016**: p. 2460285.
2. Haslam, D., *Obesity: a medical history.* Obes Rev, 2007. **8 Suppl 1**: p. 31-6.
3. Power, M.L.S., J., *The Evolution of Obesity*. 2009: The Johns Hopkins University Press. 392.
4. Ulijaszek, S.J., *Models of obesity*. First ed. 2017: Cambridge University Press. 240.
5. WHO. *World Health Organization, Obesity and overweight*. WHO Fact Sheets 2018 [cited 2019 26.10.19]; WHO Fact sheets]. Available from: https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight.
6. WOF. *World Obesity Federation; Map: Obesity prevalence worldwide - children*. 2019 [cited 2019 26.10.19]; Available from: https://www.worldobesitydata.org/.
7. Observatory, G.O., *World Obesity Federation, Global Obesity Observatory, Interactive Obesity Atlas: Obesity prevalence worldwide - Children*. 2018.
8. WHO, *Report of the Commission on Ending Childhood Obesity. Implementation plan: executive summary.* 2017, World Health Organization.
9. Epstein, L.H., et al., *Do children lose and maintain weight easier than adults: a comparison of child and parent weight changes from six months to ten years.* Obes Res, 1995. **3**(5): p. 411-7.
10. Flegal, K.M., *Commentary: the epidemic of obesity--what's in a name?* Int J Epidemiol, 2006. **35**(1): p. 72-4; discussion 81-2.
11. Swinburn, B.A., et al., *The global obesity pandemic: shaped by global drivers and local environments.* Lancet, 2011. **378**(9793): p. 804-14.
12. Foresight, *FORESIGHT Tackling Obesities: Future Choices – Obesity System Atlas*. 2007. p. Map 5.
13. Collaborators, G.B.D.O., et al., *Health Effects of Overweight and Obesity in 195 Countries over 25 Years.* N Engl J Med, 2017. **377**(1): p. 13-27.
14. OECD, *The Organization for Economic Co-operation and Development, Obesity Update 2017.* 2017: p. 4, 5.
15. Cole, T.J., et al., *Establishing a standard definition for child overweight and obesity worldwide: international survey.* BMJ, 2000. **320**(7244): p. 1240-3.
16. Cole, T.J. and T. Lobstein, *Extended international (IOTF) body mass index cut-offs for thinness, overweight and obesity.* Pediatr Obes, 2012. **7**(4): p. 284-94.
17. Juliusson, P.B., et al., *Overweight and obesity in Norwegian children: prevalence and socio-demographic risk factors.* Acta Paediatr, 2010. **99**(6): p. 900-5.
18. NIPH, *Norwegian Institute of Public Health, Barnevekststudien (Child Growth Study of Norway)*. 2016.
19. NIPH, *Norwegian Institute of Public Health, Norwegian Cause of Death Registry*. 2019.
20. Bjorge, T., et al., *Body mass index in adolescence in relation to cause-specific mortality: a follow-up of 230,000 Norwegian adolescents.* Am J Epidemiol, 2008. **168**(1): p. 30-7.
21. Aune, D., et al., *BMI and all cause mortality: systematic review and non-linear dose-response meta-analysis of 230 cohort studies with 3.74 million deaths among 30.3 million participants.* BMJ, 2016. **353**: p. i2156.
22. Must, A., S.M. Phillips, and E.N. Naumova, *Occurrence and timing of childhood overweight and mortality: findings from the Third Harvard Growth Study.* J Pediatr, 2012. **160**(5): p. 743-50.
23. Reilly, J.J. and J. Kelly, *Long-term impact of overweight and obesity in childhood and adolescence on morbidity and premature mortality in adulthood: systematic review.* Int J Obes (Lond), 2011. **35**(7): p. 891-8.
24. Ayer, J., et al., *Lifetime risk: childhood obesity and cardiovascular risk.* Eur Heart J, 2015. **36**(22): p. 1371-6.
25. Ebbeling, C.B., D.B. Pawlak, and D.S. Ludwig, *Childhood obesity: public-health crisis, common sense cure.* Lancet, 2002. **360**(9331): p. 473-82.

26. Danielsen, Y.S., et al., *Factors associated with low self-esteem in children with overweight.* Obes Facts, 2012. **5**(5): p. 722-33.
27. Gunnarsdottir, T., et al., *Teasing and social rejection among obese children enrolling in family-based behavioural treatment: effects on psychological adjustment and academic competencies.* Int J Obes (Lond), 2012. **36**(1): p. 35-44.
28. Locke, A.E., et al., *Genetic studies of body mass index yield new insights for obesity biology.* Nature, 2015. **518**(7538): p. 197-206.
29. Carnell, S., Y. Kim, and K. Pryor, *Fat brains, greedy genes, and parent power: a biobehavioural risk model of child and adult obesity.* Int Rev Psychiatry, 2012. **24**(3): p. 189-99.
30. Rutter, H., *Where next for obesity?* Lancet, 2011. **378**(9793): p. 746-7.
31. Bagnall, A.M., et al., *Whole systems approaches to obesity and other complex public health challenges: a systematic review.* BMC Public Health, 2019. **19**(1): p. 8.
32. NDH, *Norwegian Directorate of Health - Food habits in Norway 2018 - Utviklingen i norsk kosthold 2018*. 2018, Norwegian Directorate of Health.
33. Duffey, K.J. and B.M. Popkin, *Causes of increased energy intake among children in the U.S., 1977-2010.* Am J Prev Med, 2013. **44**(2): p. e1-8.
34. Bleich, S.N., R. Ku, and Y.C. Wang, *Relative contribution of energy intake and energy expenditure to childhood obesity: a review of the literature and directions for future research.* Int J Obes (Lond), 2011. **35**(1): p. 1-15.
35. Skelton, J.A., et al., *Etiologies of obesity in children: nature and nurture.* Pediatr Clin North Am, 2011. **58**(6): p. 1333-54, ix.
36. Rennie, K.L., L. Johnson, and S.A. Jebb, *Behavioural determinants of obesity.* Best Pract Res Clin Endocrinol Metab, 2005. **19**(3): p. 343-58.
37. Solberg, S.L., L. Terragni, and S.I. Granheim, *Ultra-processed food purchases in Norway: a quantitative study on a representative sample of food retailers.* Public Health Nutr, 2016. **19**(11): p. 1990-2001.
38. Blas, A., et al., *A comparison of the Mediterranean diet and current food consumption patterns in Spain from a nutritional and water perspective.* Sci Total Environ, 2019. **664**: p. 1020-1029.
39. Chi, D.L., M. Luu, and F. Chu, *A scoping review of epidemiologic risk factors for pediatric obesity: Implications for future childhood obesity and dental caries prevention research.* J Public Health Dent, 2017. **77 Suppl 1**: p. S8-S31.
40. Brug, J., et al., *Differences in weight status and energy-balance related behaviors among schoolchildren across Europe: the ENERGY-project.* PLoS One, 2012. **7**(4): p. e34742.
41. Stea, T.H., et al., *Meal pattern among Norwegian primary-school children and longitudinal associations between meal skipping and weight status.* Public Health Nutr, 2015. **18**(2): p. 286-91.
42. Bowman, S.A., et al., *Effects of fast-food consumption on energy intake and diet quality among children in a national household survey.* Pediatrics, 2004. **113**(1 Pt 1): p. 112-8.
43. Ebbeling, C.B., et al., *Compensation for energy intake from fast food among overweight and lean adolescents.* JAMA, 2004. **291**(23): p. 2828-33.
44. Emmett, P.M. and L.R. Jones, *Diet, growth, and obesity development throughout childhood in the Avon Longitudinal Study of Parents and Children.* Nutr Rev, 2015. **73 Suppl 3**: p. 175-206.
45. Shriver, L.H., et al., *Contribution of snacks to dietary intakes of young children in the United States.* Matern Child Nutr, 2018. **14**(1).
46. Basterfield, L., et al., *Physical activity, diet and BMI in children aged 6-8 years: a cross-sectional analysis.* BMJ Open, 2014. **4**(6): p. e005001.
47. Collison, K.S., et al., *Sugar-sweetened carbonated beverage consumption correlates with BMI, waist circumference, and poor dietary choices in school children.* BMC Public Health, 2010. **10**: p. 234.

48. Ebbeling, C.B., et al., *Effects of decreasing sugar-sweetened beverage consumption on body weight in adolescents: a randomized, controlled pilot study.* Pediatrics, 2006. **117**(3): p. 673-80.
49. Keller, A. and S. Bucher Della Torre, *Sugar-Sweetened Beverages and Obesity among Children and Adolescents: A Review of Systematic Literature Reviews.* Child Obes, 2015. **11**(4): p. 338-46.
50. Trumbo, P.R. and C.R. Rivers, *Systematic review of the evidence for an association between sugar-sweetened beverage consumption and risk of obesity.* Nutr Rev, 2014. **72**(9): p. 566-74.
51. Mazarello Paes, V., et al., *Determinants of sugar-sweetened beverage consumption in young children: a systematic review.* Obes Rev, 2015. **16**(11): p. 903-13.
52. Sluyter, J.D., et al., *Sizing the association between lifestyle behaviours and fatness in a large, heterogeneous sample of youth of multiple ethnicities from 4 countries.* Int J Behav Nutr Phys Act, 2013. **10**: p. 115.
53. Pate, R.R., et al., *Factors associated with development of excessive fatness in children and adolescents: a review of prospective studies.* Obes Rev, 2013. **14**(8): p. 645-58.
54. Fletcher, E., et al., *Is the relationship between sedentary behaviour and cardiometabolic health in adolescents independent of dietary intake? A systematic review.* Obes Rev, 2015. **16**(9): p. 795-805.
55. Muros, J.J., et al., *Mediterranean diet adherence is associated with lifestyle, physical fitness, and mental wellness among 10-y-olds in Chile.* Nutrition, 2017. **35**: p. 87-92.
56. SSB, *Statistics Norway, Norwegian media use 2007 - Norsk mediebarometer 2007*. 2007.
57. American Academy of Pediatrics. Committee on Public, E., *American Academy of Pediatrics: Children, adolescents, and television.* Pediatrics, 2001. **107**(2): p. 423-6.
58. SSB, *Statistics Norway: Norwegian media use 2018 - Norsk mediebarometer 2018*. 2018. p. 106.
59. York, C., *Heavy childhood television use persists into young adulthood and is associated with increased BMI.* Obesity (Silver Spring), 2016. **24**(4): p. 924-8.
60. van Ekris, E., et al., *An evidence-update on the prospective relationship between childhood sedentary behaviour and biomedical health indicators: a systematic review and meta-analysis.* Obes Rev, 2016. **17**(9): p. 833-49.
61. LeBlanc, A.G., et al., *Correlates of Total Sedentary Time and Screen Time in 9-11 Year-Old Children around the World: The International Study of Childhood Obesity, Lifestyle and the Environment.* PLoS One, 2015. **10**(6): p. e0129622.
62. Biddle, S.J., E. Garcia Bengoechea, and G. Wiesner, *Sedentary behaviour and adiposity in youth: a systematic review of reviews and analysis of causality.* Int J Behav Nutr Phys Act, 2017. **14**(1): p. 43.
63. Chaput, J.P., et al., *Electronic screens in children's bedrooms and adiposity, physical activity and sleep: do the number and type of electronic devices matter?* Can J Public Health, 2014. **105**(4): p. e273-9.
64. NDH, *Norwegian Directorate of Health: Recommendations on physical activity for children and adolescents*. 2019.
65. Miguel-Berges, M.L., et al., *Associations Between Pedometer-Determined Physical Activity and Adiposity in Children and Adolescents: Systematic Review.* Clin J Sport Med, 2018. **28**(1): p. 64-75.
66. Jimenez-Pavon, D., J. Kelly, and J.J. Reilly, *Associations between objectively measured habitual physical activity and adiposity in children and adolescents: Systematic review.* Int J Pediatr Obes, 2010. **5**(1): p. 3-18.
67. Reichert, F.F., et al., *Physical activity as a predictor of adolescent body fatness: a systematic review.* Sports Med, 2009. **39**(4): p. 279-94.
68. Kim, Y. and S. Lee, *Physical activity and abdominal obesity in youth.* Appl Physiol Nutr Metab, 2009. **34**(4): p. 571-81.

69. Niederer, I., et al., *Effects of a lifestyle intervention on adiposity and fitness in overweight or low fit preschoolers (Ballabeina).* Obesity (Silver Spring), 2013. **21**(3): p. E287-93.
70. Jimenez-Pavon, D., et al., *Association of objectively measured physical activity with body components in European adolescents.* BMC Public Health, 2013. **13**(1): p. 667.
71. Lehto, R., et al., *Health behaviors, waist circumference and waist-to-height ratio in children.* Eur J Clin Nutr, 2011. **65**(7): p. 841-8.
72. Sijtsma, A., et al., *Is directly measured physical activity related to adiposity in preschool children?* Int J Pediatr Obes, 2011. **6**(5-6): p. 389-400.
73. Ramires, V.V., S.C. Dumith, and H. Goncalves, *Longitudinal Association Between Physical Activity and Body Fat During Adolescence: A Systematic Review.* J Phys Act Health, 2015. **12**(9): p. 1344-58.
74. Javed, A., et al., *Diagnostic performance of body mass index to identify obesity as defined by body adiposity in children and adolescents: a systematic review and meta-analysis.* Pediatr Obes, 2015. **10**(3): p. 234-44.
75. Freedman, D.S. and B. Sherry, *The validity of BMI as an indicator of body fatness and risk among children.* Pediatrics, 2009. **124 Suppl 1**: p. S23-34.
76. McCarthy, H.D., et al., *Skeletal muscle mass reference curves for children and adolescents.* Pediatr Obes, 2014. **9**(4): p. 249-59.
77. Stalsberg, R. and A.V. Pedersen, *Effects of socioeconomic status on the physical activity in adolescents: a systematic review of the evidence.* Scand J Med Sci Sports, 2010. **20**(3): p. 368-83.
78. Elinder, L.S., et al., *Longitudinal changes in health behaviours and body weight among Swedish school children--associations with age, gender and parental education--the SCIP school cohort.* BMC Public Health, 2014. **14**: p. 640.
79. Nielsen, L.A., T.R. Nielsen, and J.C. Holm, *The Impact of Familial Predisposition to Obesity and Cardiovascular Disease on Childhood Obesity.* Obes Facts, 2015. **8**(5): p. 319-28.
80. Wang, Y., et al., *A Systematic Examination of the Association between Parental and Child Obesity across Countries.* Adv Nutr, 2017. **8**(3): p. 436-448.
81. Barriuso, L., et al., *Socioeconomic position and childhood-adolescent weight status in rich countries: a systematic review, 1990-2013.* BMC Pediatr, 2015. **15**: p. 129.
82. Dietz, W.H., et al., *Management of obesity: improvement of health-care training and systems for prevention and care.* Lancet, 2015. **385**(9986): p. 2521-33.
83. Knai, C., et al., *Socioeconomic patterning of childhood overweight status in Europe.* Int J Environ Res Public Health, 2012. **9**(4): p. 1472-89.
84. Chung, A., et al., *Trends in child and adolescent obesity prevalence in economically advanced countries according to socioeconomic position: a systematic review.* Obes Rev, 2016. **17**(3): p. 276-95.
85. Magnusson, M., et al., *Social Inequalities in Obesity Persist in the Nordic Region Despite Its Relative Affluence and Equity.* Curr Obes Rep, 2014. **3**: p. 1-15.
86. Lien, N., et al., *Assessing social differences in overweight among 15- to 16-year-old ethnic Norwegians from Oslo by register data and adolescent self-reported measures of socio-economic status.* Int J Obes (Lond), 2007. **31**(1): p. 30-8.
87. Quick, V., et al., *Personal, behavioral and socio-environmental predictors of overweight incidence in young adults: 10-yr longitudinal findings.* Int J Behav Nutr Phys Act, 2013. **10**: p. 37.
88. Cameron, A.J., et al., *A Review of the Relationship Between Socioeconomic Position and the Early-Life Predictors of Obesity.* Curr Obes Rep, 2015. **4**(3): p. 350-62.
89. Mielke, G.I., et al., *Socioeconomic Correlates of Sedentary Behavior in Adolescents: Systematic Review and Meta-Analysis.* Sports Med, 2017. **47**(1): p. 61-75.
90. van Stralen, M.M., et al., *Weight status of European preschool children and associations with family demographics and energy balance-related behaviours: a pooled analysis of six European studies.* Obes Rev, 2012. **13 Suppl 1**: p. 29-41.

91. Formisano, A., et al., *Family structure and childhood obesity: results of the IDEFICS Project.* Public Health Nutr, 2014. **17**(10): p. 2307-15.
92. Yannakoulia, M., et al., *Association between family divorce and children's BMI and meal patterns: the GENDAI Study.* Obesity (Silver Spring), 2008. **16**(6): p. 1382-7.
93. Wu, T., et al., *Joint effects of child temperament and maternal sensitivity on the development of childhood obesity.* Matern Child Health J, 2011. **15**(4): p. 469-77.
94. Bzostek, S.H. and L.M. Berger, *Family Structure Experiences and Child Socioemotional Development During the First Nine Years of Life: Examining Heterogeneity by Family Structure at Birth.* Demography, 2017. **54**(2): p. 513-540.
95. Dissing, A.S., et al., *Parental break-ups and stress: roles of age & family structure in 44 509 pre-adolescent children.* Eur J Public Health, 2017. **27**(5): p. 829-834.
96. Halliday, J.A., et al., *The relationship between family functioning and child and adolescent overweight and obesity: a systematic review.* Int J Obes (Lond), 2014. **38**(4): p. 480-93.
97. Lamela, D. and B. Figueiredo, *Coparenting after marital dissolution and children's mental health: a systematic review.* J Pediatr (Rio J), 2016. **92**(4): p. 331-42.
98. SSB, *Statistics Norway, Data on marriages, separations and divorces in couples with children*. 2018.
99. Musick, K. and K. Michelmore, *Cross-National Comparisons of Union Stability in Cohabiting and Married Families With Children.* Demography, 2018. **55**(4): p. 1389-1421.
100. Freitas, A., et al., *Appetite-Related Eating Behaviours: An Overview of Assessment Methods, Determinants and Effects on Children's Weight.* Ann Nutr Metab, 2018. **73**(1): p. 19-29.
101. Faber, A., L. Dube, and B. Knauper, *Attachment and eating: A meta-analytic review of the relevance of attachment for unhealthy and healthy eating behaviors in the general population.* Appetite, 2018. **123**: p. 410-438.
102. Ahren, J.C., et al., *We are family--parents, siblings, and eating disorders in a prospective total-population study of 250,000 Swedish males and females.* Int J Eat Disord, 2013. **46**(7): p. 693-700.
103. Berens, A.E., S.K.G. Jensen, and C.A. Nelson, 3rd, *Biological embedding of childhood adversity: from physiological mechanisms to clinical implications.* BMC Med, 2017. **15**(1): p. 135.
104. Weihrauch-Bluher, S., et al., *Current Guidelines for Obesity Prevention in Childhood and Adolescence.* Obes Facts, 2018. **11**(3): p. 263-276.
105. Showell, N.N., et al., *A systematic review of home-based childhood obesity prevention studies.* Pediatrics, 2013. **132**(1): p. e193-200.
106. Danielsson, P., et al., *Five-year outpatient programme that provided children with continuous behavioural obesity treatment enjoyed high success rate.* Acta Paediatr, 2016. **105**(10): p. 1181-90.
107. Waters, E., et al., *Interventions for preventing obesity in children.* Cochrane Database Syst Rev, 2011(12): p. CD001871.
108. Govindan, M., et al., *Gender differences in physiologic markers and health behaviors associated with childhood obesity.* Pediatrics, 2013. **132**(3): p. 468-74.
109. Santiago, S., et al., *Gender differences in lifestyle determinants of overweight prevalence in a sample of Southern European children.* Obes Res Clin Pract, 2013. **7**(5): p. e391-400.
110. Paus, T., et al., *Sex differences in the adolescent brain and body: Findings from the saguenay youth study.* J Neurosci Res, 2017. **95**(1-2): p. 362-370.
111. Katzmarzyk, P.T., et al., *Adiposity in children and adolescents: correlates and clinical consequences of fat stored in specific body depots.* Pediatr Obes, 2012. **7**(5): p. e42-61.
112. Demerath, E.W., et al., *Do changes in body mass index percentile reflect changes in body composition in children? Data from the Fels Longitudinal Study.* Pediatrics, 2006. **117**(3): p. e487-95.
113. Taylor, R.W., et al., *Gender differences in body fat content are present well before puberty.* Int J Obes Relat Metab Disord, 1997. **21**(11): p. 1082-4.

114. Arfai, K., et al., *Bone, muscle, and fat: sex-related differences in prepubertal children.* Radiology, 2002. **224**(2): p. 338-44.
115. Loomba-Albrecht, L.A. and D.M. Styne, *Effect of puberty on body composition.* Curr Opin Endocrinol Diabetes Obes, 2009. **16**(1): p. 10-5.
116. Karlsson, A.K., et al., *Measurements of total and regional body composition in preschool children: A comparison of MRI, DXA, and anthropometric data.* Obesity (Silver Spring), 2013. **21**(5): p. 1018-24.
117. Daniels, S.R., *The use of BMI in the clinical setting.* Pediatrics, 2009. **124 Suppl 1**: p. S35-41.
118. Wells, J.C., *Toward body composition reference data for infants, children, and adolescents.* Adv Nutr, 2014. **5**(3): p. 320S-9S.
119. Eknoyan, G., *Adolphe Quetelet (1796-1874)--the average man and indices of obesity.* Nephrol Dial Transplant, 2008. **23**(1): p. 47-51.
120. Rolland-Cachera, M.F., et al., *Adiposity indices in children.* Am J Clin Nutr, 1982. **36**(1): p. 178-84.
121. Bibiloni Mdel, M., A. Pons, and J.A. Tur, *Defining body fatness in adolescents: a proposal of the AFAD-A classification.* PLoS One, 2013. **8**(2): p. e55849.
122. McCarthy, H.D., *Body fat measurements in children as predictors for the metabolic syndrome: focus on waist circumference.* Proc Nutr Soc, 2006. **65**(4): p. 385-92.
123. Freedman, D.S., et al., *The abilities of body mass index and skinfold thicknesses to identify children with low or elevated levels of dual-energy X-ray absorptiometry-determined body fatness.* J Pediatr, 2013. **163**(1): p. 160-6 e1.
124. Cerhan, J.R., et al., *A pooled analysis of waist circumference and mortality in 650,000 adults.* Mayo Clin Proc, 2014. **89**(3): p. 335-45.
125. Jensen, N.S., T.F. Camargo, and D.P. Bergamaschi, *Comparison of methods to measure body fat in 7-to-10-year-old children: a systematic review.* Public Health, 2016. **133**: p. 3-13.
126. Burns, R., et al., *Indices of abdominal adiposity and cardiorespiratory fitness test performance in middle-school students.* J Obes, 2013. **2013**: p. 912460.
127. Brannsether, B., et al., *Waist circumference and waist-to-height ratio in Norwegian children 4-18 years of age: reference values and cut-off levels.* Acta Paediatr, 2011. **100**(12): p. 1576-82.
128. Brambilla, P., et al., *Waist circumference-to-height ratio predicts adiposity better than body mass index in children and adolescents.* Int J Obes (Lond), 2013. **37**(7): p. 943-6.
129. Mokha, J.S., et al., *Utility of waist-to-height ratio in assessing the status of central obesity and related cardiometabolic risk profile among normal weight and overweight/obese children: the Bogalusa Heart Study.* BMC Pediatr, 2010. **10**: p. 73.
130. Taylor, R.W., et al., *Predictive ability of waist-to-height in relation to adiposity in children is not improved with age and sex-specific values.* Obesity (Silver Spring), 2011. **19**(5): p. 1062-8.
131. Tuan, N.T. and Y. Wang, *Adiposity assessments: agreement between dual-energy X-ray absorptiometry and anthropometric measures in U.S. children.* Obesity (Silver Spring), 2014. **22**(6): p. 1495-504.
132. Carmienke, S., et al., *General and abdominal obesity parameters and their combination in relation to mortality: a systematic review and meta-regression analysis.* Eur J Clin Nutr, 2013. **67**(6): p. 573-85.
133. Martin-Calvo, N., L. Moreno-Galarraga, and M.A. Martinez-Gonzalez, *Association between Body Mass Index, Waist-to-Height Ratio and Adiposity in Children: A Systematic Review and Meta-Analysis.* Nutrients, 2016. **8**(8).
134. McCarthy, H.D. and M. Ashwell, *A study of central fatness using waist-to-height ratios in UK children and adolescents over two decades supports the simple message--'keep your waist circumference to less than half your height'.* Int J Obes (Lond), 2006. **30**(6): p. 988-92.
135. Tanner, J.M. and R.H. Whitehouse, *Standards for subcutaneous fat in British children. Percentiles for thickness of skinfolds over triceps and below scapula.* Br Med J, 1962. **1**(5276): p. 446-50.

136. Allison, D.B., et al., *Differential associations of body mass index and adiposity with all-cause mortality among men in the first and second National Health and Nutrition Examination Surveys (NHANES I and NHANES II) follow-up studies.* Int J Obes Relat Metab Disord, 2002. **26**(3): p. 410-6.
137. Zhu, S., et al., *Associations of body mass index and anthropometric indicators of fat mass and fat free mass with all-cause mortality among women in the first and second National Health and Nutrition Examination Surveys follow-up studies.* Ann Epidemiol, 2003. **13**(4): p. 286-93.
138. Ortega, F.B., et al., *Body Mass Index, the Most Widely Used But Also Widely Criticized Index: Would a Criterion Standard Measure of Total Body Fat Be a Better Predictor of Cardiovascular Disease Mortality?* Mayo Clin Proc, 2016. **91**(4): p. 443-55.
139. Howell, C.R., et al., *Body Composition and Mortality in Mexican American Adults: Results from the National Health and Nutrition Examination Survey.* Obesity (Silver Spring), 2018. **26**(8): p. 1372-1380.
140. Brannsether, B., et al., *References and cutoffs for triceps and subscapular skinfolds in Norwegian children 4-16 years of age.* Eur J Clin Nutr, 2013. **67**(9): p. 928-33.
141. Juliusson, P.B., et al., *Overweight and obesity in Norwegian children: secular trends in weight-for-height and skinfolds.* Acta Paediatr, 2007. **96**(9): p. 1333-7.
142. Mei, Z., et al., *Do skinfold measurements provide additional information to body mass index in the assessment of body fatness among children and adolescents?* Pediatrics, 2007. **119**(6): p. e1306-13.
143. Kakinami, L., et al., *Identifying the best body mass index metric to assess adiposity change in children.* Arch Dis Child, 2014. **99**(11): p. 1020-4.
144. Inokuchi, M., et al., *Tracking of BMI in Japanese children from 6 to 18 years of age: Reference values for annual BMI incremental change and proposal for size of increment indicative of risk for obesity.* Ann Hum Biol, 2011. **38**(2): p. 146-9.
145. Kindblom, J.M., et al., *BMI changes during childhood and adolescence as predictors of amount of adult subcutaneous and visceral adipose tissue in men: the GOOD Study.* Diabetes, 2009. **58**(4): p. 867-74.
146. Li, S., et al., *Variability and rapid increase in body mass index during childhood are associated with adult obesity.* Int J Epidemiol, 2015. **44**(6): p. 1943-50.
147. SSB, *Statistics Norway, Number of inhabitants in Bergen, 2006*. 2019.
148. SSB, *Statistics Norway, Immigrants in Bergen, 2006*. 2019.
149. Juliusson, P.B., et al., *Growth references for 0-19 year-old Norwegian children for length/height, weight, body mass index and head circumference.* Ann Hum Biol, 2013. **40**(3): p. 220-7.
150. HBSC, *Health Behaviour in School-Aged Children (HBSC) Study Protocol for the 2009/2010 Survey*. 2009. p. 182.
151. Roberts, C., et al., *The Health Behaviour in School-aged Children (HBSC) study: methodological developments and current tensions.* Int J Public Health, 2009. **54 Suppl 2**: p. 140-50.
152. Helsedirektoratet, *The Norwegian Directorate of Health, Ungkost-2000, national study on diet in schoolchildren in grade 4 and 8.* . 2002.
153. NIPH, *Norwegian Institute of Public Health, UNG-HUNT, Questionnaire*. 2000, NTNU.
154. NIPH, *Norwegian Institute of Public Health, MoBa questionnaire, Age 7 years* 2016, Norwegian Institute of Public Health.
155. Biehl, A., et al., *Parental marital status and childhood overweight and obesity in Norway: a nationally representative cross-sectional study.* BMJ Open, 2014. **4**(6): p. e004502.
156. Donkor, H.M., et al., *Social and somatic determinants of underweight, overweight and obesity at 5 years of age: a Norwegian regional cohort study.* BMJ Open, 2017. **7**(8): p. e014548.
157. Evensen, E., et al., *Tracking of overweight and obesity from early childhood to adolescence in a population-based cohort - the Tromso Study, Fit Futures.* BMC Pediatr, 2016. **16**: p. 64.

158. Skar, A., T.J. Meza, and P.M. Fredriksen, *Development of weight and height in Norwegian children: The Health Oriented Pedagogical Project (HOPP).* Scand J Public Health, 2018. **46**(21_suppl): p. 3-11.
159. Ahluwalia, N., et al., *Trends in overweight prevalence among 11-, 13- and 15-year-olds in 25 countries in Europe, Canada and USA from 2002 to 2010.* Eur J Public Health, 2015. **25 Suppl 2**: p. 28-32.
160. Kokkvoll, A., et al., *High prevalence of overweight and obesity among 6-year-old children in Finnmark County, North Norway.* Acta Paediatr, 2012. **101**(9): p. 924-8.
161. Hohwu, L., et al., *Prevalence of overweight in 2 to 17 year-old children and adolescents whose parents live separately: a Nordic cross-sectional study.* BMC Public Health, 2014. **14**: p. 1216.
162. Juliusson, P.B., *Overweight and obesity in Norwegian children. Trends, current prevalence, effect of socio-demographic factors and parental perception.* . 2010, University of Bergen. p. 73.
163. Tabachnick, B.G. and L.S. Fidell, *Using Multivariate Statistics*. 6 ed. 2014: Pearson. 1055.
164. SSB, *Statistics Norway, Population educational level, Bergen and Norway, 2007*. 2007.
165. Reinikainen, J., et al., *Participation rates by educational levels have diverged during 25 years in Finnish health examination surveys.* Eur J Public Health, 2018. **28**(2): p. 237-243.
166. Lee, E.Y. and K.H. Yoon, *Epidemic obesity in children and adolescents: risk factors and prevention.* Front Med, 2018. **12**(6): p. 658-666.
167. NIPH, *Norwegian Institute of Public Health, Armed Forces/Norhealth, Self-reported OWOB at 17 years.* 2017.
168. Fasting, M.H., et al., *Life style related to blood pressure and body weight in adolescence: cross sectional data from the Young-HUNT study, Norway.* BMC Public Health, 2008. **8**: p. 111.
169. Midthjell, K., et al., *Trends in overweight and obesity over 22 years in a large adult population: the HUNT Study, Norway.* Clin Obes, 2013. **3**(1-2): p. 12-20.
170. Cheung, P.C., et al., *Childhood Obesity Incidence in the United States: A Systematic Review.* Child Obes, 2016. **12**(1): p. 1-11.
171. Huh, D., et al., *Female overweight and obesity in adolescence: developmental trends and ethnic differences in prevalence, incidence, and remission.* J Youth Adolesc, 2012. **41**(1): p. 76-85.
172. Kim, J., et al., *Incidence and remission rates of overweight among children aged 5 to 13 years in a district-wide school surveillance system.* Am J Public Health, 2005. **95**(9): p. 1588-94.
173. Thompson, D.R., et al., *Childhood overweight and cardiovascular disease risk factors: the National Heart, Lung, and Blood Institute Growth and Health Study.* J Pediatr, 2007. **150**(1): p. 18-25.
174. Groholt, E.K., H. Stigum, and R. Nordhagen, *Overweight and obesity among adolescents in Norway: cultural and socio-economic differences.* J Public Health (Oxf), 2008. **30**(3): p. 258-65.
175. Gebremariam, M.K., et al., *Associations between socioeconomic position and correlates of sedentary behaviour among youth: a systematic review.* Obes Rev, 2015. **16**(11): p. 988-1000.
176. Overby, N.C., et al., *High intake of added sugar among Norwegian children and adolescents.* Public Health Nutr, 2004. **7**(2): p. 285-93.
177. Solberg, S.L., L. Terragni, and S.I. Granheim, *Ultra-processed food purchases in Norway: a quantitative study on a representative sample of food retailers - CORRIGENDUM.* Public Health Nutr, 2016. **19**(12): p. 2291.
178. Mitchell, J.A., et al., *Physical Activity and Pediatric Obesity: A Quantile Regression Analysis.* Med Sci Sports Exerc, 2017. **49**(3): p. 466-473.
179. Bai, Y., et al., *The Associations of Youth Physical Activity and Screen Time with Fatness and Fitness: The 2012 NHANES National Youth Fitness Survey.* PLoS One, 2016. **11**(1): p. e0148038.
180. Beauchamp, A., et al., *The effect of obesity prevention interventions according to socioeconomic position: a systematic review.* Obes Rev, 2014. **15**(7): p. 541-54.

181. Olstad, D.L., et al., *Can policy ameliorate socioeconomic inequities in obesity and obesity-related behaviours? A systematic review of the impact of universal policies on adults and children.* Obes Rev, 2016. **17**(12): p. 1198-1217.
182. Bammann, K., et al., *The impact of familial, behavioural and psychosocial factors on the SES gradient for childhood overweight in Europe. A longitudinal study.* Int J Obes (Lond), 2017. **41**(1): p. 54-60.
183. Llewellyn, A., et al., *Childhood obesity as a predictor of morbidity in adulthood: a systematic review and meta-analysis.* Obes Rev, 2016. **17**(1): p. 56-67.
184. Iannotti, R.J. and J. Wang, *Trends in physical activity, sedentary behavior, diet, and BMI among US adolescents, 2001-2009.* Pediatrics, 2013. **132**(4): p. 606-14.
185. Peltzer, K. and S. Pengpid, *Fruits and vegetables consumption and associated factors among in-school adolescents in five Southeast Asian countries.* Int J Environ Res Public Health, 2012. **9**(10): p. 3575-87.
186. Rieth, M.A., et al., *Fruits and vegetables intake and characteristics associated among adolescents from Southern Brazil.* Nutr J, 2012. **11**: p. 95.
187. Gasser, C.E., et al., *Confectionery consumption and overweight, obesity, and related outcomes in children and adolescents: a systematic review and meta-analysis.* Am J Clin Nutr, 2016. **103**(5): p. 1344-56.
188. Andersen, L.F., et al., *Overweight and obesity among Norwegian schoolchildren: changes from 1993 to 2000.* Scand J Public Health, 2005. **33**(2): p. 99-106.
189. Ross, S.E., J.I. Flynn, and R.R. Pate, *What is really causing the obesity epidemic? A review of reviews in children and adults.* J Sports Sci, 2016. **34**(12): p. 1148-53.
190. Hall, K.D., et al., *Energy balance and its components: implications for body weight regulation.* Am J Clin Nutr, 2012. **95**(4): p. 989-94.
191. Singh, R., et al., *Comparison of self-reported, measured, metabolizable energy intake with total energy expenditure in overweight teens.* Am J Clin Nutr, 2009. **89**(6): p. 1744-50.
192. Stice, E. and S. Durant, *Elevated objectively measured but not self-reported energy intake predicts future weight gain in adolescents.* Appetite, 2014. **81**: p. 84-8.
193. Cuenca-Garcia, M., et al., *More physically active and leaner adolescents have higher energy intake.* J Pediatr, 2014. **164**(1): p. 159-166 e2.
194. Thivel, D., et al., *Daily energy balance in children and adolescents. Does energy expenditure predict subsequent energy intake?* Appetite, 2013. **60**(1): p. 58-64.
195. Lioret, S., et al., *Characteristics of energy under-reporting in children and adolescents.* Br J Nutr, 2011. **105**(11): p. 1671-80.
196. Skinner, A.C., M.J. Steiner, and E.M. Perrin, *Self-reported energy intake by age in overweight and healthy-weight children in NHANES, 2001-2008.* Pediatrics, 2012. **130**(4): p. e936-42.
197. Ventura, A.K., et al., *Understanding reporting bias in the dietary recall data of 11-year-old girls.* Obesity (Silver Spring), 2006. **14**(6): p. 1073-84.
198. Pereira, H.R., et al., *Childhood and adolescent obesity: how many extra calories are responsible for excess of weight?* Rev Paul Pediatr, 2013. **31**(2): p. 252-7.
199. Wilkie, H.J., et al., *Multiple lifestyle behaviours and overweight and obesity among children aged 9-11 years: results from the UK site of the International Study of Childhood Obesity, Lifestyle and the Environment.* BMJ Open, 2016. **6**(2): p. e010677.
200. Tovar, A., et al., *Healthy-lifestyle behaviors associated with overweight and obesity in US rural children.* BMC Pediatr, 2012. **12**: p. 102.
201. Bayer, O., et al., *Fruit and vegetable consumption and BMI change in primary school-age children: a cohort study.* Eur J Clin Nutr, 2014. **68**(2): p. 265-70.
202. Carson, V., et al., *Systematic review of sedentary behaviour and health indicators in school-aged children and youth: an update.* Appl Physiol Nutr Metab, 2016. **41**(6 Suppl 3): p. S240-65.
203. Tremblay, M.S., et al., *Systematic review of sedentary behaviour and health indicators in school-aged children and youth.* Int J Behav Nutr Phys Act, 2011. **8**: p. 98.

204. Sisson, S.B., et al., *Profiles of sedentary behavior in children and adolescents: the US National Health and Nutrition Examination Survey, 2001-2006.* Int J Pediatr Obes, 2009. **4**(4): p. 353-9.
205. Robinson, T.N., et al., *Screen Media Exposure and Obesity in Children and Adolescents.* Pediatrics, 2017. **140**(Suppl 2): p. S97-S101.
206. Laxer, R.E., et al., *Behavioural patterns only predict concurrent BMI status and not BMI trajectories in a sample of youth in Ontario, Canada.* PLoS One, 2018. **13**(1): p. e0190405.
207. Gomes, T.N., et al., *Why Are Children Different in Their Daily Sedentariness? An Approach Based on the Mixed-Effects Location Scale Model.* PLoS One, 2015. **10**(7): p. e0132192.
208. Herman, K.M., et al., *Combined physical activity/sedentary behaviour associations with indices of adiposity in 8- to 10-year-old children.* J Phys Act Health, 2015. **12**(1): p. 20-9.
209. Peck, T., et al., *Viewing as little as 1 hour of TV daily is associated with higher change in BMI between kindergarten and first grade.* Obesity (Silver Spring), 2015. **23**(8): p. 1680-6.
210. Altenburg, T.M., et al., *Direction of the association between body fatness and self-reported screen time in Dutch adolescents.* Int J Behav Nutr Phys Act, 2012. **9**: p. 4.
211. Hands, B.P., et al., *The associations between physical activity, screen time and weight from 6 to 14 yrs: the Raine Study.* J Sci Med Sport, 2011. **14**(5): p. 397-403.
212. Mitchell, J.A., et al., *Time spent in sedentary behavior and changes in childhood BMI: a longitudinal study from ages 9 to 15 years.* Int J Obes (Lond), 2013. **37**(1): p. 54-60.
213. Liao, Y., et al., *Which type of sedentary behaviour intervention is more effective at reducing body mass index in children? A meta-analytic review.* Obes Rev, 2014. **15**(3): p. 159-68.
214. Olafsdottir, S., et al., *Young children's screen habits are associated with consumption of sweetened beverages independently of parental norms.* Int J Public Health, 2014. **59**(1): p. 67-75.
215. Avery, A., C. Anderson, and F. McCullough, *Associations between children's diet quality and watching television during meal or snack consumption: A systematic review.* Matern Child Nutr, 2017. **13**(4).
216. Marsh, S., C. Ni Mhurchu, and R. Maddison, *The non-advertising effects of screen-based sedentary activities on acute eating behaviours in children, adolescents, and young adults. A systematic review.* Appetite, 2013. **71**: p. 259-73.
217. Pearson, N., et al., *Associations between sedentary behaviour and physical activity in children and adolescents: a meta-analysis.* Obes Rev, 2014. **15**(8): p. 666-75.
218. Leech, R.M., S.A. McNaughton, and A. Timperio, *The clustering of diet, physical activity and sedentary behavior in children and adolescents: a review.* Int J Behav Nutr Phys Act, 2014. **11**: p. 4.
219. Baxter-Jones, A.D., et al., *The influence of physical activity on lean mass accrual during adolescence: a longitudinal analysis.* J Appl Physiol (1985), 2008. **105**(2): p. 734-41.
220. Dumith, S.C., et al., *Physical activity change during adolescence: a systematic review and a pooled analysis.* Int J Epidemiol, 2011. **40**(3): p. 685-98.
221. Reilly, J.J., *When does it all go wrong? Longitudinal studies of changes in moderate-to-vigorous-intensity physical activity across childhood and adolescence.* J Exerc Sci Fit, 2016. **14**(1): p. 1-6.
222. Carver, A., et al., *How is active transport associated with children's and adolescents' physical activity over time?* Int J Behav Nutr Phys Act, 2011. **8**: p. 126.
223. Mendoza, J.A., et al., *Active commuting to school and association with physical activity and adiposity among US youth.* J Phys Act Health, 2011. **8**(4): p. 488-95.
224. Smith, L., et al., *Is a change in mode of travel to school associated with a change in overall physical activity levels in children? Longitudinal results from the SPEEDY study.* Int J Behav Nutr Phys Act, 2012. **9**: p. 134.
225. Gebremariam, M.K., et al., *Mediators of socioeconomic differences in adiposity among youth: a systematic review.* Obes Rev, 2017. **18**(8): p. 880-898.

226. Basterfield, L., et al., *Longitudinal associations between sports participation, body composition and physical activity from childhood to adolescence.* J Sci Med Sport, 2015. **18**(2): p. 178-82.
227. De Bourdeaudhuij, I., et al., *Associations of physical activity and sedentary time with weight and weight status among 10- to 12-year-old boys and girls in Europe: a cluster analysis within the ENERGY project.* Pediatr Obes, 2013. **8**(5): p. 367-75.
228. Bergh, I.H., et al., *Personal and social-environmental correlates of objectively measured physical activity in Norwegian pre-adolescent children.* Scand J Med Sci Sports, 2011. **21**(6): p. e315-24.
229. Verstraeten, R., et al., *Predictors of validity and reliability of a physical activity record in adolescents.* BMC Public Health, 2013. **13**: p. 1109.
230. Colley, R.C., et al., *Physical activity, sedentary behaviour and sleep in Canadian children: parent-report versus direct measures and relative associations with health risk.* Health Rep, 2012. **23**(2): p. 45-52.
231. Enes, C.C. and B. Slater, *Variation in dietary intake and physical activity pattern as predictors of change in body mass index (BMI) Z-score among Brazilian adolescents.* Rev Bras Epidemiol, 2013. **16**(2): p. 493-501.
232. Dorsey, K.B., et al., *Do self- or parent-reported dietary, physical activity, and sedentary behaviors predict worsening obesity in children?* J Pediatr, 2010. **157**(4): p. 566-71.
233. Puder, J.J., et al., *Effect of multidimensional lifestyle intervention on fitness and adiposity in predominantly migrant preschool children (Ballabeina): cluster randomised controlled trial.* BMJ, 2011. **343**: p. d6195.
234. Veldhuis, L., et al., *Moderate agreement between body mass index and measures of waist circumference in the identification of overweight among 5-year-old children; the 'be active, eat right' study.* BMC Pediatr, 2013. **13**: p. 63.
235. Danielzik, S., et al., *Impact of parental BMI on the manifestation of overweight 5-7 year old children.* Eur J Nutr, 2002. **41**(3): p. 132-8.
236. SSB, *Statistics Norway, prevalence of OWOB, adults 2008.* 2008.
237. Westermair, A.L., et al., *All Unhappy Childhoods Are Unhappy in Their Own Way-Differential Impact of Dimensions of Adverse Childhood Experiences on Adult Mental Health and Health Behavior.* Front Psychiatry, 2018. **9**: p. 198.
238. Elsenburg, L.K., et al., *Accumulation of adverse childhood events and overweight in children: A systematic review and meta-analysis.* Obesity (Silver Spring), 2017. **25**(5): p. 820-832.
239. Hughes, K., et al., *The effect of multiple adverse childhood experiences on health: a systematic review and meta-analysis.* Lancet Public Health, 2017. **2**(8): p. e356-e366.
240. Arkes, J., *Longitudinal association between marital disruption and child BMI and obesity.* Obesity (Silver Spring), 2012. **20**(8): p. 1696-702.
241. Felitti, V.J., et al., *Relationship of childhood abuse and household dysfunction to many of the leading causes of death in adults. The Adverse Childhood Experiences (ACE) Study.* Am J Prev Med, 1998. **14**(4): p. 245-58.
242. Felitti, V.J., et al., *Obesity: problem, solution, or both?* Perm J, 2010. **14**(1): p. 24-30.
243. Heerman, W.J., et al., *Adverse family experiences during childhood and adolescent obesity.* Obesity (Silver Spring), 2016. **24**(3): p. 696-702.
244. Mutlu, H., et al., *Evaluation of the Relationship between Childhood Traumas and Adulthood Obesity Development.* Ecol Food Nutr, 2016. **55**(4): p. 390-401.
245. Portrie, T. and N. Hill, *Blended Families: A Critical Review of the Current Research.* The Family Journal, 2005. **13**(4): p. 445-451.
246. Amato, P.R., *The impact of family formation change on the cognitive, social, and emotional well-being of the next generation.* Future Child, 2005. **15**(2): p. 75-96.
247. Ahrons, C.R., *Family ties after divorce: long-term implications for children.* Fam Process, 2007. **46**(1): p. 53-65.

248. Mauskopf, S.S., et al., *Divorce and eating behaviors: a 5-day within-subject study of preadolescent obesity risk.* Child Obes, 2015. **11**(2): p. 122-9.
249. Byrne, L.K., et al., *Parental status and childhood obesity in Australia.* Int J Pediatr Obes, 2011. **6**(5-6): p. 415-8.
250. Langoy, A., et al., *Associations between family structure and young people's physical activity and screen time behaviors.* BMC Public Health, 2019. **19**(1): p. 433.
251. Hemmingsson, E., *Early Childhood Obesity Risk Factors: Socioeconomic Adversity, Family Dysfunction, Offspring Distress, and Junk Food Self-Medication.* Curr Obes Rep, 2018. **7**(2): p. 204-209.
252. Brannsether, B., et al., *Interrelationships between anthropometric variables and overweight in childhood and adolescence.* Am J Hum Biol, 2014. **26**(4): p. 502-10.
253. Brannsether, B., et al., *BMI and BMI SDS in childhood: annual increments and conditional change.* Ann Hum Biol, 2017. **44**(1): p. 28-33.
254. Vallgarda, S., *Childhood obesity policies - mighty concerns, meek reactions.* Obes Rev, 2018. **19**(3): p. 295-301.
255. Sabin, M.A., et al., *Viewpoint article: Childhood obesity--looking back over 50 years to begin to look forward.* J Paediatr Child Health, 2015. **51**(1): p. 82-6.

10 APPENDIX

II

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ORIGINAL RESEARCH ARTICLE

Associations between different weight-related anthropometric traits and lifestyle factors in Norwegian children and adolescents: A case for measuring skinfolds

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Abstract

Objectives: The purpose of this study was to investigate the association between weight-related anthropometric measures and children's eating habits, physical activity and sedentary lifestyle at a population level.

Methods: Data from the Bergen Growth Study were used to study the association of z-scores of waist circumference (WC), weight-to-height ratio (WHtR), subscapularis (SSF) and triceps (TSF) skinfolds and BMI, with lifestyle factors in 3063 Norwegian children (1543 boys) aged 4-15 years, using linear regression analysis. Each sex was analyzed separately.

Results: In a fully adjusted model with additional correction for BMI z-scores, the consumption of vegetables was associated with higher WC (b = 0.03) and TSF (b = 0.05) z-scores in girls. Sedentary behavior was not associated with any of the anthropometric measures. Physical activity was negatively associated with SSF (b = −0.07) and TSF (b = −0.07) z-scores in boys, while a significant negative association was observed with WC (b = −0.02), WHtR (b = −0.03), SSF (b = −0.04) and TSF (b = −0.06) in girls.

Conclusion: Physical activity was negatively associated with skinfolds in both sexes. The BMI was not related to the level of physical activity, and should be complemented with direct measures of fat tissue, like skinfolds, when studying the effect of physical activity on body composition in children.

1 | INTRODUCTION

The body mass index (BMI, kg/m^2) is by far the most frequently used measure of weight status in population studies in children and adults today. The BMI is, however, a global index of weight status that does not distinguish between fat mass and lean body mass and provides no information on the distribution of body fat (Javed et al., 2015). Body composition varies with age and sex, and an increase in BMI does not always reflect an increase in adiposity, particularly during puberty (Paus, Wong, Syme, Pausova, 2017; Katzmarzyk et al., 2012; Demerath et al. 2006). Skinfolds are direct measures of subcutaneous fat, and waist circumference (WC) or waist-to-height ratio (WHtR) are more directly related to adiposity which is in turn associated with metabolic risk (Brambilla, Bedogni, Heo, Pietrobelli, 2013; Bibiloni Mdel, Pons, Tur, 2013). Several studies have shown that WC, WHtR and skinfolds can detect excess fat in children with normal BMI, and also identify those without obesity in spite of an elevated BMI (Freedman, Ogden, Blanck, Borrud, Dietz, 2013). These measures could thus provide useful information in addition to the BMI in large population surveys, where sophisticated methods for the assessment of body composition like Dual Energy X-ray Absorptiometry (DEXA) are usually not available.

Many factors are associated with overweight and obesity in children. These include socioeconomic status (Shrewsbury, Wardle, 2008; Júlíusson et al., 2010), unhealthy eating habits such as irregular meals, snacking and the frequent consumption of sugar-containing beverages (Chi, Luu, Chu, 2017), and sedentary behavior, usually reported as screen time, TV viewing or the proxy measure of having a TV in the bedroom (Carson et al., 2016; Gebremariam et al., 2015). Results may, however, differ according to the outcome parameter under study. Skinfolds have been shown to correlate better with a diet rich in fruits and vegetables than BMI (Fletcher et al., 2015), and more closely to a Mediterranean diet than BMI or WC in girls (Muros, Cofre-Bolados, Arriscado, Zurita, Knox, 2016). Sedentary behavior has been associated with a higher BMI, while the evidence is insufficient regarding WC and skinfolds (van Ekris et al., 2016). Physical activity has been shown to be protective for the development of adiposity (Reichert, Baptista Menezes, Wells, Carvalho Dumith, Hallal, 2009; Miguel-Berges, Reilly, Moreno Aznar, Jiménez-Pavón, 2018). Most studies used the BMI as the outcome variable although skinfolds, WC and WHtR seem to be more strongly related to cardiorespiratory fitness in adolescents (Burns, Hannon, Brusseau, Shultz, Eisenman, 2013). Finally, results may also depend on the age range under study, since eating habits, sedentary behavior and physical activity have been shown to differ considerably with age and sex (Govindan et al., 2013, Santiago, Zazpe, Martí, Cuervo, Martínez, 2013).

Although studies have investigated the effect of lifestyle factors and health behavior on weight-related anthropometric measures (Giampietro et al., 2002; Niederer et al., 2013), to our knowledge, none have directly compared the association between different measures of adiposity and the level of physical activity, sedentary behavior or diet at a population level. The aim of the current study was therefore to analyze the association between lifestyle factors (eating habits, sedentary behaviors and physical activity) and five weight-related anthropometric measurements in Norwegian children and adolescents. We hypothesized that measures of central fat (WC, WHtR) and subcutaneous fat tissue (subscapular (SSF) and triceps (TSF) skinfolds) correlated better with lifestyle factors than the BMI.

2 | METHODS

2.1 | Study population

The Bergen Growth Study included in total 8299 children aged 0-19 years, recruited in a randomized, stratified selection of 34 kindergartens and 24 out of 104 schools in Bergen County between November 2003 and December 2006 (Júlíusson et al., 2010; Júlíusson et al., 2007). Data on the prevalence of overweight and obesity, socio-demographic risk factors and secular trends in weight-for-height and skinfolds have been published previously (Júlíusson et al., 2010; Júlíusson et al., 2007). The present cross-sectional study is based on a subsample of 3063 (1543 boys) children aged 4-15 years without known disorders or conditions that might affect growth, and for whom a parental questionnaire on socio-demographic and lifestyle factors was available. The questionnaire was distributed after the collection of anthropometric data, in 2006, to the parents of 7472 children included at that time point. The response rate for the parental questionnaire was 65.6% (4905 children) (Júlíusson et al., 2010). About 11% of the children had parents originating from outside the Nordic countries. The children with completed parental questionnaires had on average slightly lower z-scores for all anthropometric measures (range − 0.06 to −0.11; all $P < 0.05$), and a lower prevalence of overweight including obesity according to the International Obesity Task Force cutoffs (IOTF) (Cole, Bellizzi, Flegal, Dietz, 2000) (10.6% vs 12.6%; $P = 0.003$) compared to those who did not return the parental questionnaire.

2.2 | Anthropometric measurements

Height (cm), weight (kg), WC (cm), SSF (mm) and TSF (mm) were measured by trained health care workers using a standardized technique, as described previously (Juliusson, 2007; Brannsether, 2011). The WC was measured half-way between the lower ribs and the iliac crest, at the end of a normal expiration. The SSF was measured approximately 2 cm below the inferior angle of the left scapula. The TSF was measured midway between the acromion and caput radii of the posterior left overarm. The BMI was calculated as weight divided by height squared (kg/m^2), and the WHtR is a dimensionless parameter of waist circumference divided by height. All anthropometric traits were converted to z-scores (position of the measurement relative to the reference population, expressed as the number of standard deviations above or below the mean) according to national growth references, adjusted for sex and age (Júlíusson et al., 2013; Brannsether, Roelants, Bjerknes, Júlíusson, 2011; Brannsether, Roelants, Bjerknes, Júlíusson, 2013).

2.3 | Questionnaire

The parental questionnaire contained items on socioeconomic background and lifestyle factors. For the present analysis, the parental education level was taken as a proxy for socioeconomic status (SES). This level was classified as low (less than 12 years of education), medium (secondary school, 12 years of education) or higher education (more than 12 years of education). The questionnaire on eating habits included the frequency of the consumption of fruits, vegetables, sweets, sugar-sweetened carbonated beverages and fast-food (7 categories each), and the frequency of principal meals taken by the child. Children taking each of the four principal meals (breakfast, lunch, dinner after school, and supper later in the evening), five times or more a week, were classified as having a regular meal pattern. The questionnaire on sedentary behavior included daily screen time (hours of TV/DVD/PC per day in 6 categories) and the presence of a TV in the child's bedroom (yes/no). The physical activity questionnaire included frequency (7 categories from never to every day) and amount of sports in hours per week (6 categories) and frequency of walking and cycling to/from school.

2.4 | Statistical analysis

The distributions of the anthropometric variables are summarized by the range on the measurement scale, and by the mean and SD (SD) when converted to z-scores. Linear regression was used to analyze each of the five anthropometric measures as a dependent variable in boys and girls separately. Age was classified in 3 groups: 4-8, 9-11 and 12-15 years. Fully adjusted regression models were estimated for WC, WHtR, SSF, TSF and BMI z-scores separately, and included age, parental education and all lifestyle factors. The frequency of physical activity (times/week) was excluded from the fully adjusted model because it was highly correlated with the duration (hours/week). Finally, these models were additionally adjusted for BMI z-scores, except for the model with the BMI z-score as outcome measure. Results are reported as unstandardized regression coefficients (b) that express the effect on the original measurement scale (eg, kg/m^2 for BMI, mm for SSF etc.), with a 95% confidence interval (CI). For independent variables that are continuous or ordinal with more than 2 categories (eg, per hour physical activity per week), b is a measure of the mean change between one level and the next. For independent variables with only 2 categories (eg, irregular meals), b represents the mean difference between these categories. A P-value of 0.05 or less was considered statistically significant and a P-value of less than 0.1 as a possible (but not significant) trend, but the precise detailed effect sizes and associated P-values and 95% confidence intervals are provided in the tables. The data were analyzed using linear regression in SPSS 24.0.

2.5 | Ethics and approvals

This study was approved by the Regional Committee for Medical Research Ethics (REK 2010/3276) and the

TABLE 1 Descriptive statistics for 3063 Norwegian children in the Bergen Growth Study (2003-2006) aged 4-15 years, without conditions that affect growth, with completed questionnaires, presented according to age groups

Age-groups	4 to 8.99 year		9 to 11.99 years		12 to 15.99 years			
	N = 1325		N = 734		N = 1004		Total N = 3063 (%)	
	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls
Anthropometrics	N = 675	N = 650	N = 362	N = 372	N = 506	N = 498	N = 1543	N = 1520
Range								
WC (cm)	43.7-79.5	43.3-83.9	50.6-88.5	47.2-85.0	53.1-94.5	50.0-94.0	1540 (99.8%)	1517 (99.8%)
WHtR	0.36-0.59	0.36-0.58	0.36-0.65	0.34-0.62	0.34-0.57	0.32-0.60	1539 (99.7%)	1517 (99.8%)
SSF (mm)	2.4-32.8	3.8-33.6	3.8-34.2	4.4-31.4	4.4-28.4	4.6-37.2	1521 (98.6%)	1499 (98.6%)
TSF (mm)	4.2-27.0	4.8-26.2	5.0-27.4	5.8-32.0	3.6-33.2	4.3-33.8	1522 (98.6%)	1493 (98.2%)
BMI (kg/m2)	12.3-26.7	12.0-28.4	11.8-27.8	13.3-27.4	13.5-29.9	13.4-34.4	1539 (99.7%)	1519 (99.9%)
z-scores mean (SD)								
WC	−0.04 (1.00)	−0.01 (0.98)	0.02 (1.00)	−0.01 (0.99)	−0.10 (0.93)	−0.02 (0.97)	1540 (99.8%)	1517 (99.8%)
WHtR	−0.06 (0.99)	−0.02 (0.99)	0.03 (1.03)	−0.02 (1.04)	−0.10 (0.91)	−0.09 (0.98)	1539 (99.7%)	1517 (99.8%)
SSF	−0.05 (1.00)	−0.02 (0.98)	0.04 (1.05)	−0.05 (1.03)	−0.11 (0.96)	−0.07 (1.00)	1521 (98.6%)	1499 (98.6%)
TSF	−0.05 (1.00)	−0.01 (1.01)	−0.00 (0.96)	−0.01 (0.99)	−0.06 (0.99)	−0.04 (1.01)	1522 (98.6%)	1493 (98.2%)
BMI	−0.06 (1.01)	−0.01 (0.99)	−0.01 (1.09)	−0.07 (1.04)	−0.14 (0.97)	−0.01 (1.00)	1539 (99.7%)	1519 (99.9%)
IOTF (%)								
Overweight	60 (8.9%)	87 (13.4%)	51 (14.1%)	48 (12.9%)	44 (8.7%)	37 (7.4%)	155 (10.0%)	172 (11.3%)
Obesity	17 (2.5%)	27 (4.2%)	6 (1.7%)	9 (2.4%)	1 (0.2%)	4 (0.8%)	24 (1.6%)	40 (2.6%)
Parental education level (%)								
Primary school	29 (4.3%)	32 (4.9%)	31 (8.6%)	32 (8.6%)	22 (4.3%)	34 (6.8%)	82 (5.3%)	98 (6.4%)
Secondary school	179 (26.5%)	186 (28.6%)	109 (30.1%)	110 (29.6%)	166 (32.8%)	146 (29.3%)	454 (29.4%)	442 (29.1%)
Higher education	461 (68.3%)	427 (65.7%)	220 (60.8%)	227 (61.0%)	310 (61.3%)	313 (62.9%)	991 (64.2%)	967 (63.6%)
Physical activity (%)								
Physical activity >2 t/w	245 (36.3%)	155 (23.8%)	172 (47.5%)	99 (26.6%)	235 (46.4%)	162 (32.5%)	652 (42.3%)	416 (27.4%)
Physical activity >3 hours/w	248 (36.7%)	176 (27.1%)	200 (55.2%)	161 (43.3%)	301 (59.5%)	227 (45.6%)	749 (48.5%)	564 (37.1%)
Walk or cycle >3 t/w	345 (51.1%)	357 (54.9%)	272 (75.1%)	290 (78.0%)	214 (42.3%)	175 (35.1%)	831 (53.9%)	822 (54.1%)

Abbreviations: WC: waist circumference; WHtR: waist-to-height ratio; SSF: subscapularis skinfolds; TSF: triceps skinfolds; BMI: body mass index; SD: standard deviation; IOTF: International Obesity Task Force references; t/w: times per week; h/w: hours per week.

TABLE 2 Results from fully adjusted regression analyses of five anthropometric measures with respect to 10 personal and lifestyle factors in 1543 Norwegian boys aged 4-15 years in the Bergen Growth Study 2003-2006

Measures	WC z-scores		WHtR z-scores		SSF z-scores		TSF z-scores		BMI z-scores	
Lifestyle factors	b	95%CI	b	95%CI	b	95%CI	b	95%CI	b	95%CI
Age-groups										
4–8 years	0.093	(−0.048, 0.235)	0.093	(−0.048, 0.234)	0.129	(−0.015, 0.272)*	0.058	(−0.084, 0.199)	0.152	(**0.005, 0.299**)**
9-11 years	0.000	Reference	0.000	Reference	0.000	Reference	0.000	Reference	0.000	Reference
12-16 years	0.141	(−0.006, 0.288)*	0.159	(**0.012, 0.306**)**	0.191	(**0.042, 0.340**)**	0.107	(−0.041, 0.254)	0.151	(−0.002, 0.304)*
Parental education										
Primary school	0.006	(−0.232, 0.244)	0.031	(−0.207, 0.268)	0.192	(−0.049, 0.433)	0.070	(−0.169, 0.308)	0.059	(−0.189, 0.307)
Secondary school	0.000	Reference	0.000	Reference	0.000	Reference	0.000	Reference	0.000	Reference
Higher education	−0.073	(−0.191, 0.045)	−0.209	(**−0.326, −0.091**)**	−0.173	(**−0.293, −0.054**)**	−0.162	(**−0.280,- 0.043**)**	−0.145	(**−0.268, −0.022**)**
Eating habits										
Irregular meals (yes/no)	0.107	(−0.001, 0.215)*	0.093	(−0.015, 0.201)*	0.128	(**0.019, 0.238**)**	0.085	(−0.023, 0.194)	0.140	(**0.028, 0.253**)**
Fruit (7 levels)	0.047	(**0.005, 0.090**)**	0.017	(−0.026, 0.059)	0.014	(−0.029, 0.058)	0.017	(−0.026, 0.060)	0.030	(−0.014, 0.075)
Vegetables (7 levels)	0.007	(−0.038, 0.052)	0.004	(−0.041, 0.049)	0.011	(−0.034, 0.057)	0.002	(−0.043, 0.047)	0.025	(−0.021, 0.072)
Sweets (7 levels)	−0.079	(**−0.152, −0.007**)**	−0.045	(−0.118, 0.027)	−0.115	(**−0.190, −0.041**)**	−0.080	(**−0.154, −0.006**)**	−0.092	(**−0.167, −0.016**)**
Sugar-sweet. Drinks (7 levels)	−0.022	(−0.077, 0.034)	−0.023	(−0.079, 0.032)	−0.027	(−0.083, 0.029)	−0.024	(−0.080, 0.031)	−0.060	(**−0.117, −0.002**)**
Fast-food (7 levels)	0.067	(−0.008, 0.142)*	0.016	(−0.059, 0.091)	0.082	(**0.006, 0.158**)**	0.061	(−0.014, 0.137)	0.070	(−0.008, 0.148)
Sedentary behaviour										
Screen time (6 levels)	0.030	(−0.037, 0.098)	0.020	(−0.048, 0.087)	0.037	(−0.032, 0.106)	0.041	(−0.027, 0.110)	0.053	(−0.018, 0.123)
TV in bedroom (yes/no)	0.093	(−0.022, 0.207)	0.077	(−0.037, 0.192)	0.121	(**0.005, 0.238**)**	0.071	(−0.044, 0.186)	0.139	(**0.020, 0.259**)**
Physical activity										
Phys. activity (6 levels, h/w)	0.014	(−0.028, 0.056)	−0.012	(−0.054, 0.030)	−0.053	(**−0.096, −0.011**)**	−0.061	(**−0.103, −0.018**)**	0.020	(−0.023, 0.064)
Walk/bike to school (t/w)	−0.004	(−0.028, 0.020)	−0.015	(−0.039, 0.009)	−0.008	(−0.033, 0.016)	−0.013	(−0.037, 0.012)	−0.002	(−0.027, 0.023)

Abbreviations: WC: waist circumference; WHtR: waist-to-height ratio; SSF: subscapularis skinfolds; TSF: triceps skinfolds; BMI: body mass index; b: estimated regression coefficient; CI: confidence interval; t/w: times per week; h/w: hours per week.

*: P = 0.051-0.099; **bold****: $P \leq 0.05$.

Norwegian Data Inspectorate (9740). A signed informed consent was obtained from a parent or legal guardian of each participating child. For children above 12 years, informed assent was obtained by signature from the child.

3 | RESULTS

The distribution of the anthropometric measures by age and sex in the sample is listed in Table 1. Fully adjusted regression of demographic and lifestyle factors on the z-scores in boys and girls are listed in Tables 2 and 3. Multiple regression models with additional correction for BMI z-scores are listed in Tables 4 and 5. In the fully adjusted models, boys belonging to the oldest age group had higher WHtR and SSF z-scores, while a non-significant trend was observed for WC (Table 2). In girls, belonging to the youngest age group was only associated with higher SSF z-scores (Table 3). Higher parental education was associated with all outcomes except WC z-scores in boys, and in all outcomes in girls. After additional correction for BMI z-scores, age was no longer associated with the outcomes in boys (Table 4). In girls, belonging to the oldest age group was associated with higher SSF and TSF, and belonging to the youngest age group was also associated with higher TSF z-scores, but for SSF there was a non-significant trend (Table 5). Higher parental education remained associated with lower WHtR in boys and lower SSF and TSF in girls. BMI z-scores were associated with all the other anthropometric measures.

3.1 | Eating habits

In the fully adjusted model (Tables 2 and 3), an irregular meal pattern was associated with higher z-scores for SSF and BMI and a positive trend for WC and WHtR in boys (Table 2), and with higher z-scores for SSF and TSF and a positive trend for WHtR in girls (Table 3). The consumption of fruit was associated with higher WC in boys and the consumption of vegetables was associated with higher WC and TSF z-scores and a positive trend for SSF in girls. Higher intake of sweets was associated with lower z-scores for all outcomes except WHtR in boys, but unrelated in girls. The intake of sugar-sweetened drinks was only related to lower BMI z-scores, and fast food with higher SSF z-scores and a positive trend for WC in boys. After additional correction for BMI z-scores (Tables 4 and 5), only trends remained for boys (Table 4), and only the consumption of vegetables remained associated with higher WC and TSF z-scores in girls (Table 5).

3.2 | Sedentary behavior

In the fully adjusted models (Tables 2 and 3), there were no associations between sedentary behaviors and the outcomes, except for the presence of a TV in the bedroom and higher SSF and BMI z-scores in boys. After correction for BMI z-scores, none of these associations remained significant (Tables 4 and 5).

3.3 | Physical activity

In the fully adjusted models, a higher amount of physical activity was significantly associated with lower SSF and TSF z-scores in boys (Table 2). In girls, there was a trend indicating that walking or cycling was associated with lower WC, WHtR and TSF z-scores (Table 3). After correction for BMI z-scores, physical activity remained negatively associated with SSF and TSF z-scores, and showed a negative trend for WHtR in boys (Table 4), while a significant negative association was observed for all outcomes in girls (Table 5).

4 | DISCUSSION

The present study showed that all five weight-related anthropometric measurements studied were associated with lifestyle factors in children; however, differences were found. Eating habits were related to the BMI in boys, and irregular meals were associated with skinfolds in both sexes. Sedentary behavior was related to BMI and skinfolds in boys, but not in girls. Physical activity was only related to skinfolds in boys, but, after additional correction for BMI z-scores, higher levels of physical activity were associated with skinfolds in boys, and with all anthropometric measures in girls.

Previous findings from the Bergen Growth Study showed that the weight-related anthropometric measures were highly correlated, with WC explaining the largest part of the variance in BMI, followed by WHtR and SSF (Brannsether et al., 2014). In the obese children, all these measurements are high, while in the normal to moderate overweight range of BMI, there are larger variations (Brannsether et al., 2014). This means that anthropometric variables other than BMI have larger potential to add information in children who are normal weight or overweight than in obese children, which could be valuable in population studies. A Danish study, comparing these same anthropometric traits with percent body fat measured by Dual-X-ray absorptiometry, showed that skinfolds correlated better with percent body fat than BMI and WC (Wohlfahrt-Veje et al., 2014). In the present study, we have found that skinfolds provide useful information in addition to the BMI.

Fruit-intake was positively associated with WC in boys in the current study, and the consumption of vegetables was positively associated with WC and TSF in girls, also after correcting for BMI. These findings are in line with previous studies showing overweight being associated with higher intake of fruit and vegetables (te Velde, Twisk, Brug, 2007; Rieth, Moreira, Fuchs, Moreira, Fuchs, 2012). Further, higher intake of unhealthy foods such as sweets and sugar-

TABLE 3 Results from fully adjusted regression analyses of five anthropometric measures with respect to 10 personal and lifestyle factors in 1520 Norwegian girls aged 4-15 years in the Bergen Growth Study 2003-2006

Measures	WC z-scores		WHtR z-scores		SSF z-scores		TSF z-scores		BMI z-scores	
Lifestyle factors	**b**	**95%CI**	**b**	**95%CI**	**b**	**95%CI**	**b**	**95%CI**	**b**	**95%CI**
Age-groups										
4–8 years	0.032	(−0.105, 0.169)	0.101	(−0.038, 0.240)	0.140	(**0.000, 0.281**)**	0.084	(−0.058, 0.225)	0.036	(−0.105, 0.176)
9–11 years	0.000	Reference	0.000	Reference	0.000	Reference	0.000	Reference	0.000	Reference
12–16 years	−0.014	(−0.161, 0.133)	0.066	(−0.083, 0.216)	0.038	(−0.113, 0.189)	0.007	(−0.145, 0.159)	−0.077	(−0.228, 0.074)
Parental education										
Primary school	0.112	(−0.116, 0.340)	0.088	(−0.144, 0.320)	0.099	(−0.135, 0.332)	−0.036	(−0.268, 0.197)	0.021	(−0.212, 0.255)
Secondary school	0.000	Reference	0.000	Reference	0.000	Reference	0.000	Reference	0.000	Reference
Higher education	−0.164	(**−0.281, −0.048**)**	−0.205	(**−0.323,- 0.087**)**	−0.284	(**−0.403, −0.164**)**	−0.260	(**−0.379, −0.140**)**	−0.196	(**−0.316, −0.076**)**
Eating habits										
Irregular meals (yes/no)	0.065	(−0.045, 0.174)	0.108	(−0.002, 0.219)*	0.135	(**0.023, 0.247**)**	0.116	(**0.004, 0.229**)**	0.105	(−0.007, 0.217)
Fruit (7 levels)	−0.009	(−0.057, 0.039)	−0.017	(−0.066, 0.031)	−0.021	(−0.070, 0.028)	−0.021	(−0.070, 0.029)	0.005	(−0.044, 0.054)
Vegetables (7 levels)	0.065	(**0.016, 0.114**)**	0.030	(−0.020, 0.079)	0.046	(−0.004, 0.096)*	0.081	(**0.031, 0.131**)**	0.044	(−0.006, 0.094)
Sweets (7 levels)	−0.024	(−0.096, 0.047)	−0.042	(−0.114, 0.031)	−0.025	(−0.099, 0.048)	−0.005	(−0.079, 0.069)	−0.032	(−0.106, 0.041)
Sugar-sweet. Drinks (7 levels)	−0.038	(−0.093, 0.017)	−0.027	(−0.083, 0.029)	−0.029	(−0.085, 0.028)	−0.042	(−0.099, 0.015)	−0.054	(−0.110, 0.003)
Fast-food (7 levels	−0.029	(−0.107, 0.049)	−0.002	(−0.081, 0.077)	−0.003	(−0.083, 0.077)	0.008	(−0.073, 0.088)	−0.018	(−0.098, 0.062)
Sedentary behaviour										
Screen time (6 levels)	0.025	(−0.044, 0.093)	0.045	(−0.025, 0.114)	0.050	(−0.020, 0.120)	0.052	(−0.018, 0.122)	0.046	(−0.024, 0.116)
TV in bedroom (yes/no)	0.021	(−0.098, 0.140)	0.025	(−0.096, 0.146)	0.063	(−0.059, 0.186)	0.075	(−0.047, 0.198)	0.056	(−0.067, 0.178)
Physical activity										
Phys. activity (6 levels, h/w)	0.011	(−0.034, 0.056)	0.004	(−0.042, 0.050)	−0.007	(−0.053, 0.040)	−0.032	(−0.078, 0.015)	0.042	(−0.004, 0.089)
Walk/bike to school (t/w)	0.022	(−0.003, 0.047)*	0.022	(−0.003, 0.047)*	0.006	(−0.019, 0.032)	0.022	(−0.004, 0.048)*	0.017	(−0.008, 0.043)

Abbreviations: WC: waist circumference; WHtR: waist-to-height ratio; SSF: subscapularis skinfolds; TSF: triceps skinfolds; BMI: body mass index; b: estimated regression coefficient; CI: confidence interval; t/w: times per week; h/w: hours per week.
*: $P = 0.051$-0.099 **bold: $P \leq 0.05$.

TABLE 4 Results from fully adjusted regression analyses of four anthropometric measures with respect to 10 personal and life style factors adjusted for BMI z-scores in 1543 boys aged 4-15 years in the Bergen Growth Study 2003-2006

Measures Lifestyle factors	WC z-scores b	 95%CI	WHtR z-scores b	 95%CI	SSF z-scores b	 95%CI	TSF z-scores b	 95%CI
Age-groups								
4–8 years	−0.024	(−0.103, 0.055)	−0.008	(−0.100, 0.084)	0.018	(−0.077, 0.113)	−0.030	(−0.133, 0.072)
9–11 years	0.000	Reference	0.000	Reference	0.000	Reference	0.000	Reference
12–16 years	0.024	(−0.058, 0.106)	0.052	(−0.044, 0.148)	0.082	(−0.017, 0.181)	0.007	(−0.099, 0.113)
Parental education								
Primary school	−0.044	(−0.176, 0.089)	−0.017	(−0.172, 0.138)	0.149	(−0.011, 0.308)*	0.022	(−0.149, 0.194)
Secondary school	0.000	Reference	0.000	Reference	0.000	Reference	0.000	Reference
Higher education	0.046	(−0.020, 0.112)	−0.103	(**−0.180, −0.026**)**	−0.057	(−0.137, 0.022)	−0.066	(−0.152, 0.019)
BMI z scores	0.799	(**0.771, 0.827**)**	0.726	(**0.694, 0.759**)**	0.729	(**0.695, 0.763**)**	0.668	(**0.631, 0.704**)**
Eating habits								
Irregular meals (yes/no)	−0.007	(−0.068, 0.053)	−0.012	(−0.083, 0.059)	0.022	(−0.051, 0.095)	−0.014	(−0.092, 0.065)
Fruit (7 levels)	0.022	(−0.002, 0.046)*	−0.007	(−0.035, 0.020)	−0.010	(−0.039, 0.019)	−0.008	(−0.039, 0.023)
Vegetables (7 levels)	−0.015	(−0.040, 0.010)	−0.015	(−0.044, 0.014)	−0.010	(−0.040, 0.020)	−0.015	(−0.047, 0.018)
Sweets (7 levels)	−0.005	(−0.046, 0.036)	0.020	(−0.027, 0.068)	−0.046	(−0.096, 0.004)*	−0.020	(−0.073, 0.034)
Sugar-sweet. Drinks (7 levels)	0.028	(−0.003, 0.059)*	0.023	(−0.013, 0.059)	0.020	(−0.017, 0.058)	0.016	(−0.024, 0.056)
Fast-food (7 levels)	0.009	(−0.032, 0.051)	−0.034	(−0.083, 0.015)	0.031	(−0.020, 0.082)	0.019	(−0.035, 0.074)
Sedentary behaviour								
Screen time (6 levels)	−0.012	(−0.050, 0.026)	−0.018	(−0.062, 0.026)	−0.006	(−0.051, 0.040)	0.007	(−0.042, 0.056)
TV in bedroom (yes/no)	−0.019	(−0.083, 0.045)	−0.020	(−0.095, 0.055)	0.026	(−0.051, 0.103)	−0.008	(−0.091, 0.076)
Physical activity								
Phys. activity (6 levels, h/w)	−0.002	(−0.026, 0.021)	−0.026	(−0.053, 0.002)*	−0.069	(**−0.098, −0.041**)**	−0.071	(**−0.102, −0.041**)**
Walk/bike to school (t/w)	−0.002	(−0.015, 0.012)	0.013	(−0.029, 0.003)	−0.006	(−0.022, 0.011)	−0.011	(−0.029, 0.006)

Abbreviations: WC: waist circumference; WHtR: waist-to-height ratio; SSF: subscapularis skinfolds; TSF: triceps skinfolds; BMI: body mass index; b: estimated regression coefficient; CI: confidence interval; t/w: times per week; h/w: hours per week.
*P = 0.051-0.099; **bold****: $P \leq 0.05$.

sweetened drinks was found to be associated with lower BMI z-scores in boys. This paradoxical finding could be caused by underreporting the intake of sweets and sugar-sweetened drinks, or by a deliberate reduced intake as a consequence of (the treatment of) overweight (Gasser, Mensah, Russell, Dunn, Wake, 2016).

None of the anthropometric traits were associated with the presence of a TV in the child's bedroom after adjusting for BMI, but the BMI itself was positively associated in boys. Stamatakis et al. (2013) also found that the relation between TV viewing and BMI was stronger than the association between TV viewing and skinfolds.

SSF and TSF in boys and all anthropometric measures in girls, after adjusting for BMI, were able to detect differences in the levels of physical activity, but the BMI was not. Others have also found that physical activity is not always reflected in BMI, or to a lesser extent than in the other weight-related anthropometric measures (Niederer et al., 2013; Jiménez-Pavón et al., 2013; Sijtsma, Sauer, Stolk, Corpeleijn, 2011). McCarthy, Samani-Radia, Jebb, and Prentice (2014) found that muscular children are at high risk of being misclassified as overfat according to BMI, even young children. In a systematic review, more than 25% of children with normal BMI had excess body fat, measured by different body composition techniques (Javed et al., 2015). Other reviews found BMI to be the most frequently used outcome measure in studies on physical activity (Reichert et al., 2009; Miguel-Berges et al., 2018). Furthermore, Reichert et al. (2009) found that stable or even increased BMI could correspond to favorable changes in body composition. In line with this, skinfolds in both sexes, and WC and WHtR in girls, but not BMI, were lower in the physically active children in the current study. In our study population, girls engage less in physical activity than boys, but walk or cycle to school as often as the boys in the youngest and middle age-groups. Walking or cycling to school could, therefore, add significantly to the level of physical activity in girls, in line with other studies (Carver et al. 2011), although walking and cycling to school are by themselves not strongly associated with the anthropometric measures. Active commuting has also been linked to higher overall levels of physical activity in a prospective study (Smith et al. 2012).

The main purpose of early recognition of overweight children is to prevent the development of obesity, and the tracking of overweight and obesity from childhood to adulthood. Correct identification of children with excess fat is therefore of major importance. Adding a secondary

TABLE 5 Results from fully adjusted regression analyses of four anthropometric measures with respect to 10 personal and life style factors adjusted for BMI z-scores in 1520 girls aged 4-15 years in the Bergen Growth Study (2003-2006)

Measures	WC z-scores		WHtR z-scores		SSF z-scores		TSF z-scores	
Lifestyle factors	**b**	**95%CI**	**b**	**95%CI**	**b**	**95%CI**	**b**	**95%CI**
Age-groups								
4–8 years	0.001	(−0.072, 0.074)	0.072	(−0.012, 0.157)*	0.115	(**0.025, 0.205**)**	0.057	(−0.042, 0.155)
9-11 years	0.000	Reference	0.000	Reference	0.000	Reference	0.000	Reference
12–16 years	0.049	(−0.029, 0.127)	0.127	(**0.036, 0.217**)**	0.105	(**0.009, 0.202**)**	0.061	(−0.045, 0.167)
Parental education								
Primary school	0.103	(−0.019, 0.224)*	0.079	(−0.062, 0.220)	0.094	(−0.056, 0.243)	−0.049	(−0.211, 0.113)
Secondary school	0.000	Reference	0.000	Reference	0.000	Reference	0.000	Reference
Higher education	−0.002	(−0.064, 0.060)	−0.051	(−0.123, 0.021)	−0.131	(**−0.207, −0.054**)**	−0.117	(**−0.201, −0.033**)**
BMI z scores	0.825	(**0.798, 0.852**)**	0.784	(**0.753, 0.816**)**	0.764	(**0.730, 0.797**)**	0.709	(**0.672, 0.745**)**
Eating habits								
Irregular meals (yes/no)	−0.019	(−0.077, 0.039)	0.029	(−0.039, 0.096)	0.061	(−0.011, 0.133)	0.047	(−0.032, 0.126)
Fruit (7 levels)	−0.012	(−0.037, 0.014)	−0.021	(−0.050, 0.009)	−0.024	(−0.056, 0.007)	−0.025	(−0.060, 0.009)
Vegetables (7 levels)	0.029	(**0.003, 0.055**)**	−0.005	(−0.035, 0.025)	0.015	(−0.017, 0.047)	0.052	(**0.017, 0.087**)**
Sweets (7 levels)	0.001	(−0.037, 0.039)	−0.017	(−0.061, 0.027)	−0.006	(−0.053, 0.041)	0.015	(−0.037, 0.066)
Sugar-sweet. Drinks (7 levels)	0.007	(−0.023, 0.036)	0.016	(−0.018, 0.050)	0.016	(−0.020, 0.053)	−0.002	(−0.042, 0.038)
Fast-food (7 levels	−0.013	(−0.054, 0.029)	0.014	(−0.034, 0.062)	0.021	(−0.031, 0.072)	0.026	(−0.031, 0.083)
Sedentary behaviour								
Screen time (6 levels)	−0.015	(−0.052, 0.021)	0.007	(−0.036, 0.049)	0.010	(−0.035, 0.055)	0.013	(−0.036, 0.062)
TV in bedroom (yes/no)	−0.024	(−0.087, 0.039)	−0.018	(−0.091, 0.056)	0.024	(−0.054, 0.102)	0.032	(−0.054, 0.117)
Physical activity								
Phys. activity (6 levels, h/w)	−0.024	(**−0.048, 0.000**)**	−0.029	(**−0.057, −0.001**)**	−0.041	(**−0.071, −0.012**)**	−0.064	(**−0.096, −0.031**)**
Walk/bike to school (t/w)	−0.007	(−0.006, 0.020)	0.008	(−0.008, 0.023)	−0.006	(−0.022, 0.010)	0.011	(−0.007, 0.028)

Abbreviations: WC: waist circumference; WHtR: waist-to-height ratio; SSF: subscapularis skinfolds; TSF: triceps skinfolds; BMI: body mass index; b: estimated regression coefficient; CI: confidence interval; t/w: times per week; h/w: hours per week.
*P = 0.051-0.099; **bold****: $P \leq 0.05$.

technique to BMI screening (eg, skinfolds) could give additional information and help distinguish the children with excess fat in spite of normal BMI as well as the muscular and fit children with high BMI. However, as measuring skinfolds is technically difficult, the debate on what to use in preventive care settings is still ongoing (Javed et al., 2015). In a research setting, and in particular when assessing physical activity in children and adolescents, our data suggest skinfold measurements as a reasonable choice.

The strengths of our study include the wide age range of children included, large sample size, objectively measured anthropometric data, inclusion of five different anthropometric measures and the reasonable response rate. Further, the data include all the BMI categories, from underweight to obesity. However, some limitations need to be addressed. The cross-sectional design does not allow conclusions about causality. Further, the lifestyle factors were self-reported and collected after the anthropometric measures were performed. At last, the assessment of pubertal status was not part of the study protocol, but would have been a useful addition for the present study. While we do not believe that these limitations have hampered the conclusions drawn from our comparative analysis, the reported associations and effect sizes need confirmation in further studies. The observed effect sizes are small, illustrating obesity as a multifactorial problem with each individual lifestyle factor contributing only to a small extent.

5 | CONCLUSIONS

In this study, we compared the associations of eating habits, sedentary behavior and physical activity with anthropometric measures in boys and girls. By correcting for BMI, the additional effect of the lifestyle factors on each of the anthropometric measures could be studied. All the five weight-related anthropometric measurements included in the study were associated with lifestyle factors, albeit to a different degree. Higher levels of physical activity were associated with thinner skinfolds in both boys and girls, and in girls, also, to lower WC and WHtR, while there was no association with the BMI. Introducing supplementary anthropometric measurements, such as of skinfolds, may, therefore, increase the reliability when assessing the effect of lifestyle factors, in particular physical activity, on body composition in children and adolescents.

AUTHORS' CONTRIBUTIONS

HK was responsible for the data analysis, data interpretation and drafted the manuscript. PBJ was responsible for the study protocol, data collection and contributed to the data interpretation and the writing of the manuscript. GEE, BB and MR contributed to the data analysis, data interpretation and the writing of the manuscript. RB contributed to the data interpretation and the writing of the manuscript. All authors read and approved the final manuscript.

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REFERENCES

Bibiloni Mdel, M., Pons, A., & Tur, J. A. (2013). Defining body fatness in adolescents: a proposal of the AFAD-A classification. *PLoS One*, *8*, e55849.

Brambilla, P., Bedogni, G., Heo, M., & Pietrobelli, A. (2013). Waist circumference-to-height ratio predicts adiposity better than body mass index in children and adolescents. *International Journal of Obesity*, *37*, 943–946.

Brannsether, B., Roelants, M., Bjerknes, R., & Júlíusson, P. B. (2011). Waist circumference and waist-to-height ratio in Norwegian children 4-18 years of age: reference values and cut-off levels. *Acta Paediatrica*, *100*, 1576–1582.

Brannsether, B., Roelants, M., Bjerknes, R., & Júlíusson, P. B. (2013). References and cutoffs for triceps and subscapular skinfolds in Norwegian children 4-16 years of age. *European Journal of Clinical Nutrition*, *67*, 928–933.

Brannsether, B., Eide, G. E., Roelants, M., Bjerknes, R., & Júlíusson, P. B. (2014). Interrelationships between anthropometric variables and overweight in childhood and adolescence. *American Journal of Human Biology*, *26*, 502–510.

Burns, R., Hannon, J. C., Brusseau, T. A., Shultz, B., & Eisenman, P. (2013). Indices of abdominal adiposity and cardiorespiratory fitness test performance in middle-school students. *Journal of Obesity*, *2013*, 912460.

Carson, V., Hunter, S., Kuzik, N., Gray, C. E., Poitras, V. J., Chaput, J. P., … Tremblay, M. S. (2016). Systematic review of sedentary behaviour and health indicators in school-aged children and youth: an update. *Applied Physiology, Nutrition, and Metabolism*, *41*(Suppl 3), S240–S265.

Carver, A., Timperio, A. F., Hesketh, K. D., Ridgers, N. D., Salmon, J. L., & Crawford, D. A. (2011). How is active transport associated with children's and adolescents' physical activity over time? *International Journal of Behavioral Nutrition and Physical Activity*, *14*, 126.

Chi, D. L., Luu, M., & Chu, F. (2017). A scoping review of epidemiologic risk factors for pediatric obesity: Implications for future childhood obesity and dental caries prevention research. *Journal of Public Health Dentistry*, *77*, S8–S31.

Cole, T. J., Bellizzi, M. C., Flegal, K. M., & Dietz, W. H. (2000). Establishing a standard definition for child overweight and obesity worldwide: international survey. *BMJ*, *320*, 1240–1243.

Demerath, E. W., Schubert, C. M., Maynard, L. M., Sun, S. S., Chumlea, W. C., Pickoff, A., … Siervogel, R. M. (2006). Do changes in body mass index percentile reflect changes in body composition in children? Data from the Fels Longitudinal Study. *Pediatrics*, *117*, e487–e495.

Fletcher, E., Leech, R., McNaughton, S. A., Dunstan, D. W., Lacy, K. E., & Salmon, J. (2015). Is the relationship between sedentary behaviour and cardiometabolic health in adolescents independent of dietary intake? A systematic review. *Obesity Reviews*, *16*, 795–805.

Freedman, D. S., Ogden, C. L., Blanck, H. M., Borrud, L. G., & Dietz, W. H. (2013). The abilities of body mass index and skinfold thicknesses to identify children with low or elevated levels of dual-energy X-ray absorptiometry-determined body fatness. *The Journal of Pediatrics*, *163*, 160–166.

Gasser, C. E., Mensah, F. K., Russell, M., Dunn, S. E., & Wake, M. (2016). Confectionery consumption and overweight, obesity, and related outcomes in children and adolescents: a systematic review and meta-analysis. *The American Journal of Clinical Nutrition*, *103*, 1344–1356.

Gebremariam, M. K., Altenburg, T. M., Lakerveld, J., Andersen, L. F., Stronks, K., Chinapaw, M. J., & Lien, N. (2015). Associations between socioeconomic position and correlates of sedentary behaviour among youth: a systematic review. *Obesity Reviews*, *16*, 988–1000.

Giampietro, O., Virgone, E., Carneglia, L., Griesi, E., Calvi, D., & Matteucci, E. (2002). Anthropometric indices of school children and familiar risk factors. *Preventive Medicine*, *35*, 492–498.

Govindan, M., Gurm, R., Mohan, S., Kline-Rogers, E., Corriveau, N., Goldberg, C., … Jackson, E. A. (2013). Gender Differences in Physiologic Markers and Health Behaviors Associated With Childhood Obesity. *Pediatrics*, *132*, 468–474.

Javed, A., Jumean, M., Murad, M. H., Okorodudu, D., Kumar, S., Somers, V. K., … Lopez-Jimenez, F. (2015). Diagnostic performance of body mass index to identify obesity as defined by body adiposity in children and adolescents: a systematic review and meta-analysis. *Pediatr Obes*, *10*, 234–244.

Jiménez-Pavón, D., Fernández-Vázquez, A., Alexy, U., Pedrero, R., Cuenca-García, M., Polito, A., … HELENA Study Group. (2013). Association of objectively measured physical activity with body components in European adolescents. *BMC Public Health*, *13*, 667.

Júlíusson, P. B., Roelants, M., Eide, G. E., Hauspie, R., Waaler, P. E., & Bjerknes, R. (2007). Overweight and obesity in Norwegian children: secular trends in weight-for-height and skinfolds. *Acta Paediatrica*, *96*, 1333–1337.

Júlíusson, P. B., Eide, G. E., Roelants, M., Waaler, P. E., Hauspie, R., & Bjerknes, R. (2010). Overweight and obesity in Norwegian children: prevalence and socio-demographic risk factors. *Acta Paediatrica*, *99*, 900–905.

Júlíusson, P. B., Roelants, M., Nordal, E., Furevik, L., Eide, G. E., Moster, D., … Bjerknes, R. (2013). Growth references for 0-19 year-old Norwegian children for length/height, weight, body mass index and head circumference. *Annals of Human Biology*, *40*, 220–227.

Katzmarzyk, P. T., Shen, W., Baxter-Jones, A., Bell, J. D., Butte, N. F., Demerath, E. W., … Wells, J. C. (2012). Adiposity in children and adolescents: correlates and clinical consequences of fat stored in specific body depots. *Pediatr Obes.*, *7*, e42–e61.

McCarthy, H. D., Samani-Radia, D., Jebb, S. A., & Prentice, A. M. (2014). Skeletal muscle mass reference curves for children and adolescents. *Pediatr Obes*, *9*, 249–259.

Miguel-Berges, M. L., Reilly, J. J., Moreno Aznar, L. A., & Jiménez-Pavón, D. (2018). Associations between pedometer-determined physical activity and adiposity in children and adolescents: systematic review. *Clinical Journal of Sport Medicine*, *28*, 64–75.

Muros, J. J., Cofre-Bolados, C., Arriscado, D., Zurita, F., & Knox, E. (2016). Mediterranean diet adherence is associated with lifestyle, physical fitness, and mental wellness among 10-y-olds in Chile. *Nutrition*, *35*, 87–92.

Niederer, I., Bürgi, F., Ebenegger, V., Marques-Vidal, P., Schindler, C., Nydegger, A., … Puder, J. J. (2013). Effects of a lifestyle intervention on adiposity and fitness in overweight or low fit preschoolers (Ballabeina). *Obesity (Silver Spring)*, *21*, e287–e293.

Paus, T., Wong, A. P., Syme, C., & Pausova, Z. (2017). Sex differences in the adolescent brain and body: Findings from the saguenay youth study. *Journal of Neuroscience Research*, *95*, 362–370.

Reichert, F. F., Baptista Menezes, A. M., Wells, J. C., Carvalho Dumith, S., & Hallal, P. C. (2009). Physical activity as a predictor of adolescent body fatness: a systematic review. *Sports Medicine*, *39*, 279–294.

Rieth, M. A., Moreira, M. B., Fuchs, F. D., Moreira, L. B., & Fuchs, S. C. (2012). Fruits and vegetables intake and characteristics associated among adolescents from Southern Brazil. *Nutrition Journal*, *11*, 95.

Santiago, S., Zazpe, I., Martí, A., Cuervo, M., & Martínez, J. A. (2013). Gender differences in lifestyle determinants of overweight prevalence in a sample of Southern European children. *Obes Res Clin Pract.*, *7*, e391–e400.

Shrewsbury, V., & Wardle, J. (2008). Socioeconomic status and adiposity in childhood: a systematic review of cross-sectional studies 1990-2005. *Obesity (Silver Spring)*, *16*, 275–284.

Sijtsma, A., Sauer, P. J., Stolk, R. P., & Corpeleijn, E. (2011). Is directly measured physical activityrelated to adiposity in preschool children? *International Journal of Pediatric Obesity*, *6*, 389–400.

Smith, L., Sahlqvist, S., Ogilvie, D., Jones, A., Corder, K., Griffin, S.J., van Sluijs, E. (2012). Is a change in mode of travel to school associated with a change in overall physical activity levels in children? Longitudinal results from the SPEEDY study. *International Journal of Behavioral Nutrition and Physical Activity*, *21*, 134.

Stamatakis, E., Coombs, N., Jago, R., Gama, A., Mourão, I., Nogueira, H., … Padez, C. (2013). Associations between indicators of screen time and adiposity indices in Portuguese children. *Preventive Medicine*, *56*, 299–303.

te Velde, S. J., Twisk, J. W., & Brug, J. (2007). Tracking of fruit and vegetable consumption from adolescence into adulthood and its longitudinal association with overweight. *The British Journal of Nutrition*, *98*, 431–438.

van Ekris, E., Altenburg, T. M., Singh, A. S., Proper, K. I., Heymans, M. W., & Chinapaw, M. J. (2016). An evidence-update on the prospective relationship between childhood sedentary behaviour and biomedical health indicators: a systematic review and meta-analysis. *Obesity Reviews*, *17*, 833–849.

Wohlfahrt-Veje, C., Tinggaard, J., Winther, K., Mouritsen, A., Hagen, C. P., Mieritz, M. G., … Main, K. M. (2014). Body fat throughout childhood in 2647 healthy Danish children: agreement of BMI, waist circumference, skinfolds with dual X-ray absorptiometry. *Clinical Endocrinology*, *81*, 183–189.

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REGULAR ARTICLE

ACTA PÆDIATRICA NURTURING THE CHILD WILEY

Norwegian children and adolescents in blended families are at risk of larger one-year BMI increments

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Abstract

Aim: To study how sociodemographic factors and family structure associate with baseline BMI z-scores (BMIz) and BMIz change in 767 Norwegian children aged 6-15 years.

Methods: Baseline BMIz and 1-year BMIz increments in children from the Bergen Growth Study were analysed with linear and logistic regression, according to sociodemographic factors and family structure. A blended family was defined as including a step-parent and/or half-sibling.

Results: In a fully adjusted regression model, baseline BMIz were only significantly associated with maternal BMI (b = 0.087, 95%CI 0.067, 0.107). Body Mass Index z-scores increments were larger in children living in a blended family (b = 0.060, 95%CI 0.006, 0.115), with a lower parental education (b = 0.127, 95%CI 0.029, 0.226) and with a higher maternal BMI (b = 0.008, 95%CI 0.001, 0.014). The odds for a large BMIz increment (>1 SD) were higher in children living in blended families (OR 1.82, 95%CI 1.16, 2.88) and with higher maternal BMI (OR 1.07, 95%CI 1.01, 1.13) and lower in 9-11-year-old children (OR 0.44, 95%CI 0.26, 0.77) compared with 12-15-year-olds.

Conclusion: Body Mass Index z-scores increments were more strongly associated with sociodemographic factors and living in a blended family than baseline BMIz values. BMI z-scores increments could be useful for identifying children at risk of becoming overweight or obese.

KEYWORDS
BMI, divorce, family type, maternal factors, overweight

1 | INTRODUCTION

The causes of the childhood obesity epidemic are multifactorial and include a lifestyle with unhealthy eating habits[1] and more sedentary behaviour.[2] However, the child's family and social situation have also been found to be important, with low parental educational level,[3] high parental BMI [4] and family break-up [5] as known factors that are associated with overweight. Moreover, children that have experienced divorce, or children living with step-parents, are more prone to have problems in the domains of academic achievement, psychological well-being, self-esteem, and peer relations and frequently have weaker emotional bonds with their parents.[6]

About 50% of children of married parents experience family break-up before reaching the age of 18 years, making this a

Abbreviations: BMI, body mass index; BMI increments, increase in BMI; Blended family, a family including a step-parent and/or half-siblings; IOTF, international obesity taskforce; OR, odds ratio; SD, standard deviation; 95%CI, 95% confidence interval.

frequent childhood stressor.[7] Cohabiting parents, representing about 50% of parents in Norway, split up at twice the rate of married parents,[7,8] but only a few studies have included cohabiting parents' break-up in addition to divorce and the blended family structure as a stressor.[9,10] In most studies, these families are categorised as single-parent families, although the child's life could be very different in a blended family with a step-parent and/or half-siblings.[6]

The objective of our study was to investigate the effect of sociodemographic factors and family structure on the BMI and 1-year BMI increments in children aged 5.5-15 years. We hypothesised that children living in single parent or blended families are at risk for larger 1-year BMI increments.

Key notes

- Body mass index (BMI) z-score increments could be useful to identify children with an ongoing risk of developing overweight.
- Maternal BMI and parental education were associated with larger 1-year BMI increments.
- One-year BMI increments were also larger in children living in blended families.

2 | METHODS

2.1 | Study population

The Bergen Growth Study (BGS) is a mixed longitudinal study, with follow-up measurements 1 year after the baseline measurement in a subset of school-aged children, allowing the study of BMI increments.[11] A total of 8299 children aged 0-19 years were recruited and measured between November 2003 and December 2006 in a random selection of 34 days care centres and 19 schools in Bergen country.[12] In a subsample of seven schools, children were invited for a second measurement after 12 months (plus/minus 1 month), between October 2005 and March 2006. Anthropometric data were available at baseline and at 1-year follow-up in 1209 children. The parental questionnaire was distributed in August 2006 and a reminder was sent in January 2007. The response rate for the parental questionnaire was 67%, but somewhat lower in the children above 12 years of age (53%).[12] About half of the questionnaires were returned by September 2006, and 97% by March 2007. For the present analysis, we included 767 children for whom the parental questionnaire was returned, excluding 15 children with a disease that could affect growth, three with a second measurement before 11 months or after 13 months, 19 children with an age outside of the range of 5.5-15 years, and two children with incomplete data for BMIz at baseline.

2.2 | Anthropometric measurements/ BMI increments

Height and weight were measured by trained healthcare workers using a standardised technique, as described previously.[12] The BMI was calculated as weight divided by height squared (kg/m^2) and converted to BMI z-scores (BMIz) based on the national BMI reference.[12] A BMIz increment was defined as the difference between BMIz after 1 year and BMIz at baseline, not adjusted for the time interval. A positive BMIz increment was defined as a higher BMIz after 1 year than at baseline. Weight status (normal weight, overweight, obesity) was determined by the IOTF criteria [13] at baseline and after 1 year. Overweight includes obesity, and normal weight includes underweight throughout the text. Mother's and father's BMI were calculated from self-reported height and weight.

2.3 | Questionnaire

The parental questionnaire contained items on the sociodemographic background and family structure. The parental educational level was classified as low (primary school; <12 years of education), medium (secondary school; 12 years of education) and high (higher education; more than 12 years of education). We used maternal BMI rather than paternal or mean parental BMI since the BMI of the mother is more closely correlated with childhood overweight,[4] and less often missing (6.6%) than paternal BMI (15.9%). Family structure was categorised in three groups: blended families, defined by the

TABLE 1 Descriptive statistics of children from the Bergen Growth Study included in the present analysis

	Number (% or SD) N = 767
IOTF at baseline (%) (n = 767)	
Normal BMI and underweight	640 (83.4%)
Overweight/obese	127 (16.6%)
Mean baseline BMIz (SD)	0.01 (1.03)
Mean BMI z-score after 1 y (SD)	0.04 (1.03)
BMIz increments (n = 767)	
Mean increments[a] (SD)	0.03 (0.32)
N with BMIz increase (%)	424 (55.3%)
N with BMIz decrease or stable (%)	343 (45.5%)
BMIz increments above +1 SD[b] (%)	125 (16.3%)
Normal BMI and underweight	112 (14.6%)
Overweight/obese	13 (1.7%)
Parental BMI >25 (%) (n = 581)	
Maternal BMI >25	234 (40.3%)
Paternal BMI >25	382 (65.8%)
Both parents BMI >25	149 (25.7%)

Abbreviations: BMIz, BMI z-score; N, number; SD, standard deviation; y, years.
[a]Paired *t* test 0.33 (0.001-0.06).
[b]>+1 SD corresponds to >0.32 BMIz in our dataset.

presence of a step-parent and/or half-sibling(s), single-parent families and nuclear families.

The prevalence of overweight was lower in children who answered the questionnaire (10.6%) compared to those who did not (12.6%), which is a statistically significant difference ($P = .003$; chi-squared test for independence), but with a small effect size (Cramer's V: 0.05).

2.4 | Statistical analysis

Baseline BMIz and BMIz increments were analysed with linear regression models according to sociodemographic and family factors. Models for BMIz increments were adjusted for baseline BMIz to correct for regression to the mean. Baseline BMIz and maternal BMI were entered into the models as continuous variables, and the other variables as categorical. Results are presented for partially adjusted models (adjusted only for baseline BMIz) and fully adjusted regression models. Relevant interactions were tested and added if statistically significant. The Levene test of equality of error variances was significant, which could indicate that linear regression was not the best option, but the difference in variance was not large and visual inspection of residual plots showed only limited heteroscedasticity. We therefore chose to keep the linear models, which can be interpreted as (confounder) adjusted mean differences between groups. Results of the linear regression analyses are reported as unstandardised regression coefficients (B) that express the effect on the original measurement scale (eg maternal BMI) with a 95% confidence interval (CI). For independent variables with more than two categories (eg age groups), B is a measure of the mean difference between one level and the reference category. Logistic regression was used to examine the association between family structure and large BMIz increments, taking other sociodemographic factors into account. A large BMIz increment was defined as >1 SD, which corresponds to a change in BMI z-score between baseline and follow-up of 0.32 units. Results are expressed as odds ratios with corresponding 95% confidence intervals (CI).

Changes in mean increments and differences in BMI increments between children with normal weight or overweight were analysed with *t* tests, and the prevalence of a high parental BMI in children with normal weight or with overweight was analysed with a chi-squared test.

A *P*-value of .05 or less was considered statistically significant. The data were analysed using SPSS 24.0.

3 | RESULTS

The prevalence of overweight and obesity according to the criteria of the International Obesity Taskforce (IOTF) [13] was 12.5% and 4.0%, respectively, at baseline and 15.2% and 2.6% after 1 year (chi-square $P < .001$). There were only few children with obesity in our study group (n = 31), and none in the oldest age group (12-15 years) (Table 1). A majority of parents (64%) had a higher educational level, and 29%

TABLE 2 Linear regression of five sociodemographic and family variables on BMI z-score at baseline; 2 models: unadjusted and adjusted. No significant interactions

		BMIz at baseline			
		Unadjusted (N = 701)		Fully adjusted (N = 701)	
	N = 767 (%)	B	95% CI	B	95% CI
Boys vs girls	373 (48.6%)	−0.061	−0.207; 0.086	−0.470	−0.192; 0.097
Age groups					
5.5-8 y	327 (42.7%)	0.108	−0.078; 0.294	0.124	−0.061; 0.308
9-11 y	253 (33.1%)	0.056	−0.140; 0.252	0.079	−0.115; 0.273
12-15 y	185 (24.2%)	Ref.			
Parental education					
Primary school	57 (7.5%)	−0.209	−0.509; 0.092	−0.118	−0.424; 0.188
Secondary school (12 y)	219 (28.7%)	0	Ref.	0	Ref.
Higher education	487 (63.8%)	−0.182	−0.346; −0.018[a]	−0.129	−0.292; 0.034
Maternal BMI	581 (75.8%)	0.090	0.071; 0.110[a]	0.087	0.067; 0.107[a]
Family structure					
Blended family	196 (25.9%)	0.023	−0.148; 0.194	0.007	−0.162; 0.177
Single parent	61 (8.1%)	−0.060	−0.335; 0.215	0.000	−0.269; 0.268
Nuclear family	500 (66.1%)	Ref.			

Note: Blended family: the presence of a step-parent and/or half-siblings.
Abbreviations: BMIz, BMI z-score; N, number; SD, standard deviation; Y, years.
[a]Significant at 0.05 level.

TABLE 3 Linear regression of five sociodemographic and family variables on BMI z-score increments after 1 year; 2 models: adjusted for baseline BMI z-score and fully adjusted. No significant interactions

		BMIz increments			
		Adjusted for baseline BMIz N = 767		Fully adjusted N = 701	
	N = 767 (%)	B	95% CI	B	95% CI
Baseline BMIz	767 (100%)	−0.109	−0.138; −0.079[a]	−0.053	−0.077; −0.028[a]
Boys vs girls	373 (48.6%)	0.014	−0.032; 0.060	−0.002	−0.049; 0.045
Age groups					
5.5-8 y	327 (42.7%)	0.029	−0.030; 0.088	0.005	−0.055; 0.064
9-11 y	253 (33.1%)	−0.024	−0.085; 0.038	−0.041	−0.103; 0.022
12-15 y	185 (24.2%)	Ref.		Ref.	
Parental education					
Primary school	57 (7.5%)	0.109	0.016; 0.202[a]	0.127	0.029; 0.226[a]
Secondary school (12 y)	219 (28.7%)	0	Ref.	0	Ref.
Higher education	487 (63.8%)	0.027	−0.024; 0.078	0.042	−0.011; 0.095
Maternal BMI	581 (75.8%)	0.008	0.002; 0.015[a]	0.008	0.001; 0.014[a]
Family structure					
Blended family	196 (25.9%)	0.070	0.017; 0.124[a]	0.060	0.006; 0.115[a]
Single parent	61 (8.1%)	0.005	−0.080; 0.091	0.019	−0.067; 0.106
Nuclear family	500 (66.1%)	Ref.		Ref.	

Note: Blended family: the presence of a step-parent and/or half-siblings.
Abbreviations: BMIz, BMI z-score; N, number; SD, standard deviation; Y, years.
[a]Significant at 0.05 level.

had completed secondary school. In this sample, 11.2% of the children had at least one parent originating from outside of Norway.

Body Mass Index z-score increments were smaller in children with overweight (−0.05 ± 0.30) than in children with normal weight (0.05 ± 0.32), (*t* test *P* < .001). The BMIz increased (positive increment) in a total of 424 children (55.3%) (Table 1), of whom 13% were children with overweight and 87% were children with a normal weight at baseline.

Both parents had a BMI above 25 in 46% of children with overweight at baseline, compared to 17% in children with normal weight. Maternal overweight was present in 58% of children with overweight compared to 28% in children with a normal weight. Paternal overweight was present in 81% and 55% of children, respectively (chi-square *P* < .001 for all). The overall prevalence is presented in Table 1.

One in four children lived in a blended family (n = 196, 26%), 61 (8%) in a single-parent family, 500 (66%) in a nuclear family and 10 (1%) in another type of family (7 of them with grandparents) (Table 2). Out of the 70 children (9%) living with a step-parent, 64 (91%) lived with a step-father. In 52 families (7%), the child lived with both a step-parent and half-siblings, and in 126 families (16%) the child had half-siblings, but did not live with a step-parent.

3.1 | BMIz at baseline

In the unadjusted linear regression models, a high parental education was associated with lower baseline BMIz whereas higher maternal BMI was associated with higher baseline BMIz (Table 2). In the fully adjusted linear regression model, only maternal BMI was associated with higher baseline BMIz (Table 2).

3.2 | BMIz increments after 1 year

Baseline BMIz were associated with lower BMIz increments (Table 3). A low parental education, high maternal BMI and a living in a blended family were associated with larger BMIz increments in both partially (adjusted for baseline BMIz only) and fully adjusted linear regression models (Table 3).

3.3 | Large (>1 SD) BMIz increments (logistic regression)

A high baseline BMI was associated with lower BMIz increments and vice versa. The odds for a large BMIz increment were also lower in children aged 9-11 years compared with children aged 12-15 years, and higher in the presence of a high maternal BMI and in children living in a blended family in both partially (adjusted for baseline BMIz) and fully adjusted logistic regression models (Table 4).

3.4 | Interpretation of results

For a boy aged 15 and living in a blended family (b = 0.06, Table 3), the BMI would increase with approximately 0.2 kg/m^2 over the course

TABLE 4 Binary logistic regression of 5 sociodemographic and family variables on large BMIz increments (> +1 SD[b]), corrected for baseline BMI z-score. No significant interactions

		Binary logistic regression of BMIz >1 SD[b]			
		Adjusted for baseline BMIz		Fully adjusted	
		N = 767		N = 701	
	N = 767 (%)	OR	95% CI	OR	95% CI
Baseline BMIz	767 (100%)	0.71	0.59; 0.86[a]	0.65	0.52; 0.81[a]
Boys vs girls	373 (48.6%)	1.25	0.85; 1.84	1.34	0.89; 2.03
Age groups					
5.5-8 y	327 (42.7%)	0.65	0.41; 1.02	0.67	0.41; 1.09
9-11 y	253 (33.1%)	0.43	0.25; 0.72[a]	0.44	0.26; 0.77[a]
12-15 y	185 (24.2%)	1	Ref.	1	Ref.
Parental education					
Primary school	57 (7.5%)	1.62	0.78; 3.38	1.80	0.79; 4.08
Secondary school (12 y)	219 (28.7%)	1	Ref.	1	Ref.
Higher education	487 (63.8%)	1.07	0.68; 1.68	1.20	0.74; 1.94
Maternal BMI	581 (75.8%)	1.07	1.01; 1.13[a]	1.07	1.01; 1.13[a]
Family structure					
Blended family	196 (25.9%)	1.93	1.26; 2.96[a]	1.82	1.16; 2.88[a]
Single parent	61 (8.1%)	1.59	0.80; 3.16	1.67	0.83; 3.38
Nuclear family	500 (66.1%)	1	Ref.	1	Ref.

Note: Blended family: the presence of a step-parent and/or half-siblings.
Abbreviations: BMIz, BMI z-score; N, number; SD, standard deviation; Y, years.
[a]Significant at 0.05 level.
[b]>+1 SD corresponds to >0.32 BMIz in our dataset.

of 1 year (BMI SD in boys aged 16 is 2.6 in our material), which corresponds to a surplus increase in body weight of about 0.6 kg. While this gain may appear small, so is that of other well-known risk factors to which it should be added.

4 | DISCUSSION

In the present study, 1-year BMIz increments and large (>1 SD) BMIz increments were associated with parental education, maternal BMI and living in a blended family. Baseline BMIz was also associated with parental education and maternal BMI, but not with family structure. To our knowledge, this is the first study to compare BMIz and BMIz increments in relation to family structure. Our study underlines the importance of follow-up measurements for the early identification of children at risk for an undesired weight development.

Body Mass Index z-score increments have been shown to be a good proxy for fat mass change in children.[14] An annual BMIz increment of 2 SD was suggested as a cut-off for identifying Japanese children at risk of obesity,[11] and a BMIz change of + 1 SD in childhood and adolescence was shown to predict higher fat mass in Swedish young adult men.[15] Identifying factors associated with weight increase in childhood could therefore be important in order to prevent childhood overweight.

A new finding of our study is the association between an ongoing increase in BMIz and living in a blended family. Family break-up is one of the stressors included in the adverse childhood events (ACEs) and is associated with childhood overweight.[16] ACEs have been related to childhood overweight [16-18] and overall poor health outcome, including obesity in adulthood.[19] The connection between family structure and childhood overweight could be mediated through both physiologic and lifestyle factors.[20] Children who have experienced parental break-up spend more time with screens,[5] drink more sugar-sweetened drinks,[21] and have more unhealthy eating habits, including the use of food for comfort.[5,21] Arkes found an increased risk of overweight 2 years prior to, and up to 6 years after a family break-up,[17] which could be the result of a parental conflict that may continue for years after the separation.[6,22] The presence of a step-parent could also be challenging for the child because of the inevitable adjustment to one or more new family members. Even though the presence of a step-parent usually results in an improved financial situation and parents may be able to spend more time with their children, it could also result in new rules and routines, or moving away from home, school or friends. In addition, the relationship with family members may become tense if the child experiences loyalty conflicts or a strained relationship with the step-parent.[6] Portrie [23] reviewed the literature on blended families and found that step-parents, and especially stepfathers, monitored stepchildren less closely than biological parents, which could have important implications regarding their lifestyle. Stepchildren tend to perceive discipline from step-parents as more harsh, which could raise conflict and introduce stress. In the end, especially cohabiting (ie not married) step-parents may have difficulties in finding their role in the family.[23] Children living in a blended family could thus be exposed to several risk factors for increased weight gain, if stress that results from adjusting to a new stepfamily is added to unhealthy lifestyle factors and stress related to family conflict.

In a Nordic study,[24] no association was found between family break-up and childhood overweight, but the authors concluded that this might have been due to selection bias because the response rate was very low. In a more recent study,[25] with an equally low response rate, no association was found between family break-up and cardiometabolic risk factors in adolescence apart from smoking and alcohol consumption. Unfortunately, a low response rate might not occur at random,[26] and the risk of underestimating the association of risk factors with overweight is therefore real. While the overall response rate in our study was acceptable, the slightly lower prevalence of overweight in questionnaire respondents indicates that selection bias cannot be excluded, but it is probably small. The association between a blended family structure and BMIz increments in our study is small in terms of effect size, but as family break-up and a blended family structure are becoming more common, we believe this to be a risk factor that warrants further investigation.

In our study, we did not find any association between a single-parent family structure and BMIz increments. Children living with a single parent have earlier been reported to have higher BMIz and higher stress levels than those living in blended or nuclear families,[9,10] but these studies did not account for the presence of half-siblings which somewhat hampers the comparison with the single-parent category in our study.[24,27] A single-parent family could be the result of a divorce, but it could also result from the loss of a parent or simply be the original intended family context, and we therefore chose to keep this as a separate group. A blended family could be a different stressor than divorce,[28] as the child will have to adjust to new family members. Formisano [9] found that the presence of a step-parent was a protective factor compared to a single parent, but in our study there was no difference in BMIz at baseline or BMIz increments for the children living only with a step-parent and those also living with half-siblings (data not shown).

In our study, the child's sex or age was not associated to BMIz at baseline or BMIz increments, and in the logistic regression analysis of large BMIz increments, age, but not sex, was related. There was no interaction between the child's age and family structure in our data, which suggests that children were not more vulnerable at certain ages. This is in agreement with Dissing,[10] who found that age was unrelated to stress levels when studying divorce in children up to the age of 11 but contrary to Bzostek [29] who found that children aged 3 to 9 years were the most vulnerable to the negative effects of divorce in terms of behavioural problems. Unfortunately, we did not have information about the timing of the family break-up or the introduction of the stepfamily members which would have been an interesting addition regarding the timing of the unfavourable weight development.[6,17]

In accordance with other studies,[3,30] we found an association between parental educational level and the BMI in their offspring. A higher parental education was associated with a lower baseline BMIz, whereas a lower parental education was associated with larger BMIz increments. Furthermore, we observed a non-significant trend of increased risk for large BMIz increments in children of low-educated parents. The association between socioeconomic status and BMI could be mediated through lifestyle,[31] and parental education level is also linked to family structure [9] as there is generally a higher risk of separation among less-educated couples.[8]

Maternal BMI was found related both to baseline BMIz and to positive BMIz increments after a year in our study. While we found that both maternal and paternal BMI were associated with the BMI in offspring, only the maternal BMI was retained in the analysis to avoid the exclusion of children for whom no paternal data were available. The prevalence of maternal and paternal overweight in our data is comparable with the population prevalence at the time,[7] so our data seem reasonably representative in this respect.

There are some limitations to the present study. Children of parents with a high education level were over-represented in our study, about double compared to the national census estimate.[7] Families with shared parenting, about 10%-25% of children at this time,[7] are classified as nuclear families in our dataset, and this could lead to an underestimation of the association in the single-parent group. Other single parents are in the group of blended families, for example if the child has a half-sibling from a previous parental relation, but the parent currently is single. If we had information about step-siblings, we could have included more families in the blended family group. Also, we had no information about the time of break-up or the time of introduction of the step-parent. Finally, the parental BMI was calculated from self-reported height and weight. Strengths of the study are the longitudinal design, the relatively large number of otherwise healthy children with a wide age-range in the sample, and the fact that the questionnaire included more detailed information about blended families, when compared to many other studies, as we had information about step-parents and half-siblings. Moreover, we used a broad definition of family break-up by including blended families from cohabiting relationships (by using the variables step-parents and half-siblings), while other studies have used divorce ([5,9,27]).Therefore, the prevalence of family break-up in our data (26%) was much higher compared to a previous study in Norway (7%) which only included divorce,[27] but still below the expected prevalence of about 50%.[7]

The prevalence of overweight including obesity has been shown to increase from about 22% in children and adolescents to 60%-75% in adulthood, and that of obesity from about 7% in children to 20%-25% in adults.[32] Therefore, most future adults with overweight or obesity come from the group of children with a normal weight.[33] Body Mass Index z-score increments could be an important tool to identify children at risk for a gradual increase in weight. Combining this information with the sociodemographic and family background has the potential to further refine the search for children at risk, with the aim of prevention.[34]

5 | CONCLUSIONS

In the present study, we found that children living in a blended family as well as children with a high maternal BMI had larger BMIz increments, which should warrant attention in the preventive setting. BMIz increments allow us to monitor ongoing changes in weight and could be valuable to identify children at risk for developing overweight.

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CONFLICT OF INTEREST

The authors declare that they have no competing interests.

ETHICAL APPROVAL

This study was approved by the Regional Committee for Medical Research Ethics (REK 2010/3276) and the Norwegian Data Inspectorate (9740). A signed informed consent was obtained from a parent or legal guardian of each participating child. For children above 12 years, informed assent was obtained by signature also from the child.

DATA AVAILABILITY STATEMENT

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REFERENCES

1. Ross SE, Flynn JI, Pate RR. What is really causing the obesity epidemic? A review of reviews in children and adults. *J Sports Sci*. 2016;34:1148-1153.
2. Tremblay MS, LeBlanc AG, Kho ME, et al. Systematic review of sedentary behaviour and health indicators in school-aged children and youth. *Int J Behav Nutr Phys Act*. 2011;8:98.
3. Chung A, Backholer K, Wong E, Palermo C, Keating C, Peeters A. Trends in child and adolescent obesity prevalence in economically advanced countries according to socioeconomic position: a systematic review. *Obes Rev*. 2016;17:276-295.
4. Nielsen LA, Nielsen TR, Holm JC. The impact of familial predisposition to obesity and cardiovascular disease on childhood obesity. *Obes Facts*. 2015;8:319-328.
5. Yannakoulia M, Papanikolaou K, Hatzopoulou I, Efstathiou E, Papoutsakis C, Dedoussis GV. Association between family divorce and children's BMI and meal patterns: the GENDAI Study. *Obesity (Silver Spring)*. 2008;16:1382-1387.
6. Amato PR. The impact of family formation change on the cognitive, social, and emotional well-being of the next generation. *Future Child*. 2005;15:75-96.
7. SSB Statistics Norway (cited April 11th, 2019). Available from https://www.ssb.no/statbank/. Accessed April 11, 2019.
8. Musick K, Michelmore K. Cross-national comparisons of union stability in cohabiting and married families with children. *Demography*. 2018;55:1389-1421.
9. Formisano A, Hunsberger M, Bammann K, et al. Family structure and childhood obesity: results of the IDEFICS Project. *Public Health Nutr*. 2014;17:2307-2315.
10. Dissing AS, Dich N, Andersen AN, Lund R, Rod NH. Parental breakups and stress: roles of age & family structure in 44 509 pre-adolescent children. *Eur J Public Health*. 2017;27:829-834.
11. Inokuchi M, Matsuo N, Takayama JI, Hasegawa T. Tracking of BMI in Japanese children from 6 to 18 years of age: reference values for annual BMI incremental change and proposal for size of increment indicative of risk for obesity. *Ann Hum Biol*. 2011;38:146-149.
12. Juliusson PB, Roelants M, Nordal E, et al. Growth references for 0–19 year-old Norwegian children for length/height, weight, body mass index and head circumference. *Ann Hum Biol*. 2013;40:220-227.
13. Cole TJ, Bellizzi MC, Flegal KM, Dietz WH. Establishing a standard definition for child overweight and obesity worldwide: international survey. *BMJ*. 2000;320:1240-1243.
14. Kakinami L, Henderson M, Chiolero A, Cole TJ, Paradis G. Identifying the best body mass index metric to assess adiposity change in children. *Arch Dis Child*. 2014;99:1020-1024.
15. Kindblom JM, Lorentzon M, Hellqvist A, et al. BMI changes during childhood and adolescence as predictors of amount of adult subcutaneous and visceral adipose tissue in men: the GOOD Study. *Diabetes*. 2009;58:867-874.
16. Elsenburg LK, van Wijk K, Liefbroer AC, Smidt N. Accumulation of adverse childhood events and overweight in children: a systematic review and meta-analysis. *Obesity (Silver Spring)*. 2017;25:820-832.
17. Arkes J. Longitudinal association between marital disruption and child BMI and obesity. *Obesity (Silver Spring)*. 2012;20:1696-1702.
18. Heerman WJ, Krishnaswami S, Barkin SL, McPheeters M. Adverse family experiences during childhood and adolescent obesity. *Obesity (Silver Spring)*. 2016;24:696-702.
19. Felitti VJ, Jakstis K, Pepper V, Ray A. Obesity: problem, solution, or both? *Perm J*. 2010;14:24-30.
20. Berens AE, Jensen S, Nelson CA 3rd. Biological embedding of childhood adversity: from physiological mechanisms to clinical implications. *BMC Med*. 2017;15:135.
21. Mauskopf SS, O'Leary AK, Banihashemi A, Weiner M, Cookston JT. Divorce and eating behaviors: a 5-day within-subject study of preadolescent obesity risk. *Child Obes*. 2015;11:122-129.
22. Hayatbakhsh R, Clavarino AM, Williams GM, Bor W, O'Callaghan MJ, Najman JM. Family structure, marital discord and offspring's psychopathology in early adulthood: a prospective study. *Eur Child Adolesc Psychiatry*. 2013;22:693-700.
23. Portrie T, Hill N. Blended families: a critical review of the current research. *Fam J Alex Va*. 2005;13:445-451.
24. Hohwu L, Gissler M, Sjoberg A, Biehl AM, Kristjansson AL, Obel C. Prevalence of overweight in 2 to 17 year-old children and adolescents whose parents live separately: a Nordic cross-sectional study. *BMC Public Health*. 2014;14:1216.

25. Soares A, Goncalves H, Matijasevich A, et al. Parental separation and cardiometabolic risk factors in late adolescence: a cross-cohort comparison. *Am J Epidemiol*. 2017;185:898-906.
26. Rosendahl KI, Sundblom E, Elinder LS. Trajectories of weight disturbances during adolescence in relation to gender in a Swedish cohort. *Acta Paediatr*. 2012;101:300-307.
27. Biehl A, Hovengen R, Groholt EK, Hjelmesaeth J, Strand BH, Meyer HE. Parental marital status and childhood overweight and obesity in Norway: a nationally representative cross-sectional study. *BMJ Open*. 2014;4:e004502.
28. Ahrons CR. Family ties after divorce: long-term implications for children. *Fam Process*. 2007;46:53-65.
29. Bzostek SH, Berger LM. Family structure experiences and child socioemotional development during the first nine years of life: examining heterogeneity by family structure at birth. *Demography*. 2017;54:513-540.
30. Magnusson M, Sorensen TI, Olafsdottir S, et al. Social inequalities in obesity persist in the Nordic region despite its relative affluence and equity. *Curr Obes Rep*. 2014;3:1-15.
31. Cameron AJ, Spence AC, Laws R, Hesketh KD, Lioret S, Campbell KJ. A review of the relationship between socioeconomic position and the early-life predictors of obesity. *Curr Obes Rep*. 2015;4:350-362.
32. Midthjell K, Lee CM, Langhammer A, et al. Trends in overweight and obesity over 22 years in a large adult population: the HUNT Study, Norway. *Clin Obes*. 2013;3:12-20.
33. Geserick M, Vogel M, Gausche R, et al. Acceleration of BMI in early childhood and risk of sustained obesity. *N Engl J Med*. 2018;379:1303-1312.
34. Reinehr T. Lifestyle intervention in childhood obesity: changes and challenges. *Nat Rev Endocrinol*. 2013;9:607-614.

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