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

Hege Kristiansen | Geir Egil Eide | Bente Brannsether | Mathieu Roelants | Robert Bjerknes | Pétur B. Júlíusson

1Department of Pediatrics, District General Hospital of Førde, Førde, Norway
2Department of Clinical Science, Section for Pediatrics, University of Bergen, Bergen, Norway
3Centre for Clinical Research, Haukeland University Hospital, Bergen, Norway
4Department of Global Public Health and Primary Care, Research Group for Lifestyle Epidemiology, University of Bergen, Bergen, Norway
5Department of Pediatrics, Stavanger University Hospital, Stavanger, Norway
6Environment and Health, Department of Public Health and Primary Care, KU Leuven – University of Leuven, Leuven, Belgium
7Department of Pediatrics, Haukeland University Hospital, Bergen, Norway

Correspondence
Pétur B. Júlíusson MD, PhD, Department of Clinical Science, University of Bergen, N-5021 Bergen, Norway. Mobile number: +47 97777079. Email: petur.juliusson@uib.no

Funding information
The Bergen Growth Study has been supported by the Western Norway Regional Health Authority and the University of Bergen. HK has received grants from the Western Norway Regional Health Authority and Førde Health Authority.

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/m²) 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 (Júlíusson, 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/m² 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 | Total N = 3063 (%) |
|------------|----------------|-----------------|------------------|-----------------|
|            | N = 1325      | N = 734         | N = 1004         | N = 1543        |
|            | Boys = 675    | Girls = 650     | Boys = 362       | Girls = 372     |
|            | Boys = 506    | Girls = 498     | Boys = 1543      | Girls = 1520    |
| Anthropometrics |           |                 |                  |
|                | Range         | z-scores mean (SD) |                  |
| WC (cm)       | 43.7-79.5     | 50.6-88.5       | 50.1-94.5        | 1540 (99.8%)    |
| WHtR          | 0.36-0.59     | 0.36-0.65       | 0.34-0.57        | 1539 (99.7%)    |
| SSF (mm)      | 2.4-32.8      | 3.8-34.2        | 4.4-28.4         | 1521 (98.6%)    |
| TSF (mm)      | 4.2-27.0      | 5.0-27.4        | 3.6-33.2         | 1522 (98.6%)    |
| BMI (kg/m2)   | 12.3-26.7     | 11.8-27.8       | 13.5-29.9        | 1539 (99.7%)    |
| Overweight (%)| 60 (8.9%)     | 51 (14.1%)      | 48 (12.9%)       | 155 (10.0%)     |
| Obesity (%)   | 17 (2.5%)     | 6 (1.7%)        | 9 (2.4%)         | 24 (1.6%)       |
| Parental education level (%)|       |                 |                  |
| Primary school| 29 (4.3%)     | 31 (8.6%)       | 32 (8.6%)        | 82 (5.3%)       |
| Secondary school| 179 (26.5%)  | 110 (29.6%)     | 146 (29.3%)      | 454 (29.4%)     |
| Higher education| 461 (68.3%) | 227 (61.0%)     | 313 (62.9%)      | 991 (64.2%)     |
| Physical activity (%)|   |                 |                  |
| Physical activity ≥2 times/week | 245 (36.3%) | 99 (26.6%)      | 235 (46.4%)      | 652 (42.3%)     |
| Physical activity ≥3 hours/week | 248 (36.7%) | 205 (52.5%)     | 227 (45.6%)      | 749 (48.5%)     |
| Walk or cycle ≥3 times/week | 345 (51.1%) | 272 (75.1%)     | 175 (35.1%)      | 831 (53.9%)     |

**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                     | Age-groups          | WC z-scores b | 95% CI          | WHtR z-scores b | 95% CI          | SSF z-scores b | 95% CI          | TSF z-scores b | 95% CI          | BMI z-scores b | 95% CI          |
|------------------------------|---------------------|---------------|-----------------|-----------------|-----------------|---------------|----------------|---------------|----------------|---------------|----------------|
|                              | 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: subscapular 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-
| Measures/ Lifestyle factors | WC z-scores | WHtR z-scores | SSF z-scores | TSF z-scores | BMI z-scores |
|----------------------------|-------------|---------------|--------------|--------------|-------------|
| Age-groups                 | b | 95%CI | b | 95%CI | b | 95%CI | b | 95%CI | b | 95%CI |
| 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: subscapular 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* ≤ 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-Radja, Jebb, and Prentice (2014) found that muscular children are at high risk of being misclassified as overweight 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 |
|-------------------|-------------|---------------|--------------|--------------|
|                    | 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   | −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 ≤ 0.05.

The 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.

ORCID

Pétur B. Júlíusson https://orcid.org/0000-0002-7064-1407

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.
Braunsether, 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.
Braunsether, 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.
Braunsether, 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., Brasseux, 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., Lau, 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 cardio-metabolic health in adolescents independent of dietary intake? A systematic review. Obesity Reviews, 16, 795–805.
Freedman, D. S., Ogden, C. L., Blanck, H. M., Boruud, 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, 998–1000.
Giampietro, O., Virgione, E., Carnevali, L., Griese, 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., Juneman, 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. Pediatric Obes, 10, 234–244.
Jiménez-Pavón, D., Fernández-Vázquez, A., Alexy, U., Pedrozo, 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. Pediatric Obes., 7, e42–e61.
McCarthy, H. D., Samani-Radia, D., Jebb, S. A., & Prentice, A. M. (2014). Skelatal muscle mass reference curves for children and adolescents. Pediatr Obes, 9, 249–259.
Miguel-Borges, 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.
Niedner, L., Burgi, F., Ebeneberger, 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 (Ballabinea). Obesity (Silver Spring), 21, e287–e293.
Paus, T., Wong, A. P., Syne, 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.
Riet, 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. I., Stolk, R. P., & Copelieijn, 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., Attenburg, 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.

How to cite this article: 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;30:e23187. [https://doi.org/10.1002/ajhb.23187](https://doi.org/10.1002/ajhb.23187)