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Sexual Dimorphism of Brown Adipose Tissue Function

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Objective To determine whether brown adipose tissue (BAT) activity in school-age children differs between the sexes and to explore the impact of dietary intake, sedentary behavior, and picky/fussy eating.

Study design Children aged 8.5-11.8 years of age (n = 36) underwent infrared thermography to determine the temperature of the skin overlying the main superficial BAT depot in the supraclavicular region before and after 5 minutes of mild cold exposure (single-hand immersion in cool tap water at about 20°C). The relationships between the supraclavicular region temperature and parental reports of food consumption, eating behavior, and inactivity were explored.

Results The supraclavicular region temperature was higher in boys (n = 16) at baseline, and after cold exposure. Boys displayed a greater thermogenic response to cold. Strong negative correlations were observed between the supraclavicular region temperature and body mass index percentile, and differences in supraclavicular region temperature between girls and boys persisted after adjustment for body mass index percentile. A negative linear relationship was observed between protein and vegetable intake and supraclavicular region temperature in girls only, but did not persist after adjustment for multiple comparisons. There was no difference in the adjusted supraclavicular region temperature between active or inactive children, or picky and nonpicky eaters.

Conclusions These findings indicate sexual dimorphism in BAT thermogenic activity and a sex-specific impact of diet. Future studies should aim to quantify the contribution of BAT to childhood energy expenditure, energy imbalance, and any role in the origins of childhood obesity. *(J Pediatr 2019;210:166-72)*.

Globally, more than 124 million school-age children are now classified as overweight or obese[1] and, as a consequence, are at risk of significant cardio-metabolic disease in adulthood.[2,3] The individual components of childhood energy balance are poorly understood, and the impact of brown adipose tissue (BAT) on energy expenditure, has yet to be quantified.

BAT persists outside the neonatal period into childhood and beyond. Increasing evidence suggests that this highly metabolic, thermogenic tissue contributes to energy expenditure by oxidizing lipids and glucose.[4-7] This is achieved by the dissipation of chemical energy as heat through the action of mitochondrial uncoupling protein (UCP)1. Histologic evidence of BAT has been demonstrated in children in the neck, upper thorax, mediastinum,[8,9] and in the adipose tissue surrounding the heart[10] and kidneys[8,11] as well as subcutaneously.[11] It is estimated that just 63 g of adult BAT could combust the energy equivalent of 4.1 kg of white adipose tissue over the course of a year.[12] Because the prevalence and activity of BAT are higher throughout infancy[9,13] and childhood,[14] the relative contribution of BAT to bioenergetic metabolism may be even greater in infants and children than in adulthood.

Although associations between dietary intake and sedentary behaviors, such as television viewing, on white adipose tissue (ie, obesity) have been widely reported, their effects on BAT has not. The methods for the measurement of supraclavicular skin temperature using thermal imaging present an ethically acceptable, noninvasive, repeatable method for BAT assessment in children and have been repeatedly shown to reflect measurements of BAT activity as assessed on positron emission tomography-computed tomography (PET-CT) scanning.[15-17]

Sexual dimorphism in both BAT mass and its activity has been comprehensively reviewed in adults[18,19] and, despite similar distribution of depots throughout the body, premenopausal women seem to have more BAT than men,[20,21] implicating a role for hormonal regulation. Data in infants and children are less clear.[11,14,22-27] Gilsanz et al report a higher BAT mass, increased BAT activity, and more rapid increase in BAT during the pubertal growth spurt in boys, as compared with girls.[14] Although glucose is used during BAT thermogenesis, the primary substrates for brown adipocytes at the cellular level are fatty

BAT	Brown adipose tissue
BMI	Body mass index
FDG	Fluorodeoxyglucose
MCSDS	Marlowe–Crowne Social Desirability Scale
SCAT	Subcutaneous adipose tissue
UCP1	Uncoupling protein 1

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acids. The functional assessment of BAT beyond that of glucose uptake is integral to understanding how BAT may be regulated and its contribution to energy expenditure in early life.

Given the potential importance of BAT activity in metabolic health, our aim was to determine whether the sexual dimorphism observed in adults exists between girls and boys at baseline and in response to a brief mild cold stimulus[28,29] when infrared thermography of the supraclavicular skin temperature is used as a measure of BAT thermogenic activity. In addition, because diet and habitual physical activity influence metabolic health, we sought to identify whether parental reports of dietary intake, picky eating behavior, and television viewing were associated with differences in BAT activity in a sex-specific manner.

Methods

This study was approved by the University of Nottingham's School of Medicine Ethics Committee (E10012013 SCS ACH TREAT). Participants were recruited from 2 Nottingham City schools over a period of 3 weeks, and data collection was undertaken between April and June 2013. There were no specific eligibility criteria other than the requirement for parental written consent and receipt of children's verbal consent for anthropometry and imaging. Parents/guardians gave informed written consent for participation in this study, and all children gave additional verbal assent. Thirty-six children were imaged under free-living conditions within a primary school environment.

Infrared thermography of the neck and upper thorax was undertaken as previously described.[28] In brief, the reflective temperature, ambient room temperature, and humidity were measured before each imaging session and entered into the thermal camera according to manufacturer's instructions. Supraclavicular temperature is also related to ambient temperature,[28] and ambient room temperatures were stable during the study (Table I). Each child sat 0.8 m away from the thermal camera (FLIR B425FLIR Systems AB, Danderyd, Sweden) for 5 minutes wearing a sleeveless cotton vest. BAT in children responds to very mild cold stimulation[28-30] and participants next immersed their left hand in cool tap water (about 20°C) for 5 minutes, producing a similar decrease in hand temperature in girls and boys (Table I). Images were taken at intervals throughout the study with comparable subject positioning. Thermograms obtained 1 minute before hand immersion and 5 minutes after hand immersion were analyzed to calculate the supraclavicular region temperature. Values were defined as baseline supraclavicular region temperature and cold-exposed supraclavicular region temperature, respectively, and the thermogenic response to cold as the change in supraclavicular region temperature (calculated as the cold-exposed supraclavicular region temperature minus the baseline supraclavicular region temperature). For the purposes of image analysis, the supraclavicular region was defined as the region of skin visible between the acromioclavicular joint, sternal notch, and contour of the shoulder. Only thermograms where both left and right supraclavicular regions were completely exposed and unobstructed by clothing or hair, and where clavicles were positioned perpendicular to the camera lens, were regarded as acceptable for analysis.

The radiometric data obtained from thermograms were converted to temperature data within MATLAB (2017, MathWorks, Natick, Massachusetts) using a script adapted as described by Law et al[15]. The thermal image was displayed on a graphical user interface, allowing identification of 5 points representing the apices of the supraclavicular region as defined elsewhere in this article. The supraclavicular region temperature was calculated as the 95th percentile temperature value of the supraclavicular region of interest.[15,29,31]

To determine the baseline temperature of the skin not overlying BAT, a region away from the proximity of supraclavicular BAT visible in all children's thermograms was chosen as a comparator. This anatomic region, the center of the

Table I. Demographic and anthropometric variables in healthy girls and boys aged 8-11 years (n = 36)*

Variables	Boys (n = 16)	Girls (n = 20)	*P* value
Age, decimal years	9.9 (0.24)	8.5 (0.23)	.62
Height, cm	138.8 (2.0)	139.0 (1.7)	.94
Weight, kg	31.81 (1.33)	34.89 (1.72)	.12
BMI percentile	48.36 (8.00)	59.57 (6.63)	.28
Ambient temperature, °C	22.01 (0.20)	22.10 (0.14)	.71
Supraclavicular region temperature before cold exposure, °C	36.02 (−0.14)	35.63 (−0.12)	.03
Supraclavicular region temperature after cold exposure, °C	36.17 (−0.14)	35.62 (−0.12)	.004
T_{mp} before cold exposure, °C	32.96 (−0.25)	33.13 (−0.31)	.65
T_{mp} after cold exposure, °C	33.36 (−0.22)	33.09 (−0.27)	.46
Hand temperature decrease, °C (n = 28; 16 female and 12 male)	−8.85 (−0.30)	−8.00 (−0.57)	.20
Television watching, h	2.12 (0.26)	2.20 (0.24)	.84
Picky eater, yes	8/16	11/20	.76
Food consumption score, Likert-item group sum†			
Protein	61.69 (2.67)	63.60 (2.13)	.57
Vegetable	84.94 (4.66)	86.45 (2.85)	.77

T_{mp}, Mandibular prominence temperature.
*Contaminated by socially desirable responding.
†Food consumption score: higher numerical value = lower consumption.

anterior mandibular protuberance, was identified visually using FLIR's proprietary software, ResearchIR version 4 (FLIR Systems AB, Danderyd, Sweden). The mean temperature value of an 86-pixel area ellipse (mandibular prominence temperature) was calculated before and after cold exposure (using the same thermograms as for the calculation of supraclavicular region temperature). To confirm, and quantify, the degree of hand cooling, the temperature of the left hand before, and immediately after, cooling was calculated for each subject using the mean value of an individualized maximally sized ellipse fitted to the anatomic area bound by the metacarpophalangeal joints and radial–ulnar styloid processes on the dorsum of the hand. Nine of the 36 children analyzed for this study did not have thermograms of the left hand before or after hand immersion. The mandibular prominence temperature and hand temperature were calculated using the standard ellipse region-of-interest tool in ResearcherIR version 4 (FLIR Systems AB, Danderyd, Sweden).

The parents of each child completed questionnaires regarding their child's food intake, and were asked to rate their child's frequency of consumption of 151 foods (adapted from Wardle et al[32]) from 1 to 8 (1 [more than once a day] to 7 [less than once a month] and 8 [never eaten]). Responses were grouped into 7 standard food categories as described previously[33] and summed to create a score for each food group for each child. Each food group consisted of between 9 and 20 items.

Where consumption of a food was rated as never in more than 25% of children, that food was excluded from grouped analysis.[32] The remaining foods were grouped into the following categories: (1) carbohydrate, (2) dairy, (3) fruit, (4) protein, (5) savory, (6) sweet, and (7) vegetable. The Cronbach alpha was calculated for each group as a measure of the internal consistency of the scale. Reliability was acceptable (Cronbach alpha > 0.7[34]) for all groups except dairy (0.54) for the food consumption questionnaires. The food consumption score, as a sum for each food group, was calculated for each child and compared with indices of supraclavicular temperature (ie, baseline supraclavicular region temperature, cold-exposed supraclavicular region temperature, and the change in supraclavicular region temperature) derived from thermograms as described elsewhere in this article.

To identify children with fussy eating behavior, parents were asked if they would classify their child as a "picky eater." Parents were also asked to estimate their child's duration of television exposure per day to the nearest half an hour. Those children reported as watching 2 or more hours a day were classed as sedentary and those watching less than 2 hours television a day as active.

To ensure responses were not contaminated by socially desirable responding, parents also completed a short form of the Marlowe–Crowne Social Desirability Scale (MCSDS).[35] Analysis of the MCSDS identified that food consumption scores were not contaminated by socially desirable responding. However, MCSDS scores were significantly correlated with the estimated number of hours of television watched.

Height was measured to the nearest 0.1 cm using a stadiometer (Leicester height measure; Child Growth Foundation, Sutton Coldfield, UK) and weight to the nearest 0.1 kg using a standard, calibrated weighing scale. Body mass index (BMI) percentile was calculated to adjust for sex and age using the National Health Service Choices BMI calculator.[36] Height, weight, and BMI percentile for the children in this study are summarized in **Table I**.

Statistical Analyses

Data were analyzed using SPSS V.24 (IBM, Armonk, New York). Data are mean ± SE and normally distributed (as assessed by the Shapiro-Wilk normality test) unless stated otherwise. Comparisons between left and right supraclavicular region temperature were performed using the paired *t* test. Percentages were compared using the χ^2 test. Pearson product-moment correlation coefficients were calculated to determine the correlation between supraclavicular region temperature and food exposure scores and supraclavicular region temperature and BMI percentile. A 2-way mixed ANOVA was conducted to examine the effects of sex and cold exposure on supraclavicular region temperature. Post hoc comparisons were undertaken using the *t* test. ANCOVA was performed to determine the effect of sex and cold exposure on supraclavicular region temperature after controlling for BMI percentile. A 2-way ANCOVA was conducted to examine the effects of sex and sedentary behavior, and sex and picky eating behavior, on supraclavicular region temperature after controlling for BMI percentile.

A sample size of 30 (15 boys and 15 girls) was calculated to detect a 25% difference in the supraclavicular skin temperature (ie, the change in supraclavicular region temperature) in response to cold exposure, based on previously published data from healthy children of comparative age[28] (ie, right the change in supraclavicular region temperature 0.28 ± 0.064°C [mean ± SD]; $\beta = 0.2$; $\alpha = 0.05$).

A *P* value of less than 0.05 (2 tailed) was considered statistically significant. To account for multiple testing during calculation of Pearson correlation coefficient, the false discovery rate was controlled using the corrected method of Benjamini and Yekutieli[37] with the desired false discovery rate of 5%. Full details of the statistical analysis are included in the online **Appendix**.

Results

The skin temperature overlying supraclavicular BAT was higher in boys at baseline, after cold exposure, and there was a greater change in temperature response to cold exposure, which was significant in boys but not girls (**Figure**). Consistent with this, sex had a statistically significant effect on the supraclavicular region temperature response to cold exposure, right supraclavicular region temperature: $F(1,34) = 6.37$, $P = .016$, partial $\eta^2 = 0.16$; left supraclavicular region temperature, $F(1,34) = 6\ .41$, $P = .016$, partial $\eta^2 = 0.16$.

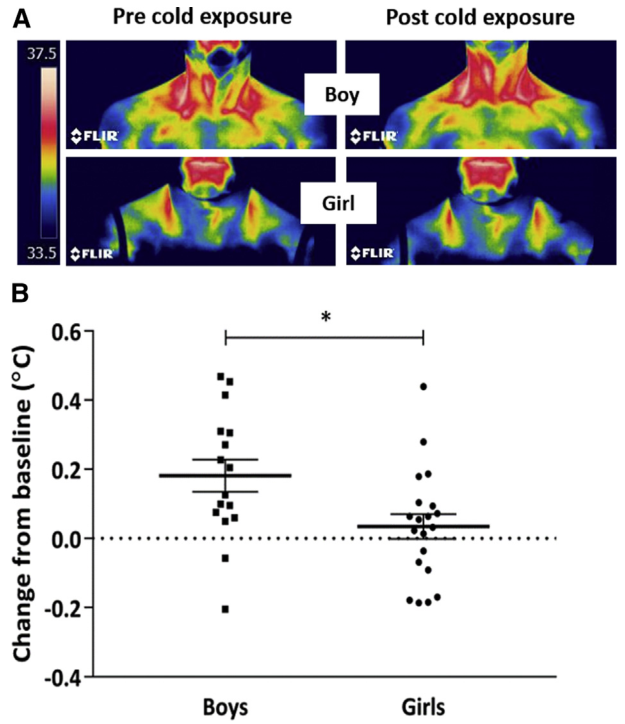

Figure. Change in supraclavicular skin temperature after 5 minutes of a single hand immersion in cool water. **A,** Representative anterior thermal images of a girl and boy (matched for age and BMI percentile) at baseline and after cold exposure. **B,** Left-sided change in supraclavicular temperature after 5 minutes cold exposure in healthy girls and boys aged 8-11 years (n = 36). Post hoc pair-wise comparisons: right supraclavicular region temperature, $F(1,15) = 11.38$, $P = .004$, partial $\eta^2 = 0.43$; left supraclavicular region temperature, $F(1,15) = 15.16$, $P = .007$, partial $\eta^2 = 0.50$. *$P < .05$. *FLIR*, forward looking infrared.

Because a significant negative linear relationship was observed between supraclavicular region temperature and BMI centile (r = −0.71 to −0.43; $P < .01$), even after correction for multiple comparisons (data not shown).

The adjusted cold-exposed supraclavicular region temperature was statistically higher in boys than girls (right supraclavicular region temperature mean difference, 0.41°C [95% CI, 0.14-0.68°C]; left supraclavicular region temperature mean difference, 0.41°C [95% CI, 0.12-0.70°C]); however, the similar trend in baseline supraclavicular region temperature did not maintain statistical significance, right supraclavicular region temperature, $F(1,33) = 3.48$, $P = .07$, partial $\eta^2 = 0.10$; left supraclavicular region temperature, $F(1,33) = 3.46$, $P = .07$, partial $\eta^2 = 0.10$. However, thermogenic response to cold exposure (the change in the supraclavicular region temperature) remained greater in boys (right supraclavicular region temperature mean difference, 0.14°C [95% CI, 0.02-0.26°C]); left the change in supraclavicular region temperature mean difference, 0.14°C [95% CI, 0.02-0.25°C]). The adjusted means for supraclavicular region temperature at baseline, after cold exposure and for the change in supraclavicular region temperature, are summarized in **Table II**.

A significant negative linear relationship between the supraclavicular region temperature and parental report of vegetable and protein consumption was observed in girls. However, these relationships were no longer statistically significant after adjustment for multiple testing in our study sample. There were no associations between supraclavicular region temperature and food consumption in any category in boys (**Table III**) and no difference in vegetable and protein consumption scores between girls and boys (**Table I**).

Sixty-one percent of children were reported to watch 2 or more hours of television per day, but there was no significant difference between boys and girls (**Table I**). There was no effect of sex and sedentary behavior (classified as ≥2 hours of television per day) on supraclavicular region temperature after controlling for the effect of BMI percentile and no statistically significant 2-way interaction between sex and sedentary behavior, while controlling for BMI percentile (**Table IV**; available at www.jpeds.com).

Therefore, an analysis of the main effects of sedentary behavior and sex was performed. There was no statistically significant difference in unweighted marginal adjusted means

Table II. Unadjusted means (SEM) for left and right supraclavicular skin temperatures and means (SEM) adjusted for BMI percentile* in healthy girls and boys before and after 5 minutes of cold exposure (n = 36)

	Supraclavicular skin temperature (°C)					
	Baseline		Cold exposure		Change in supraclavicular region temperature	
	Boys	Girls	Boys	Girls	Boys	Girls
Unadjusted means (SEM)						
Left supraclavicular region temperature	35.88†,‡ (0.13)	35.47‡ (0.13)	36.06†,‡,§ (0.14)	35.51‡ (0.13)	0.18†,‡ (0.05)	0.03‡ (0.04)
Right supraclavicular region temperature	36.02† (0.14)	35.63 (0.12)	36.17†,§ (0.14)	35.62 (0.12)	0.15† (0.04)	−0.002 (0.04)
Adjusted means (SEM)*						
Left supraclavicular region temperature	35.81 (0.11)	35.53 (0.10)	35.98 (0.11)	35.57 (0.10)	0.17 (0.04)	0.04 (0.04)
Right supraclavicular region temperature	35.95 (0.11)	35.68 (0.10)	36.10 (0.10)	35.68 (0.09)	0.14 (0.04)	0.02 (0.04)

*ANCOVA, BMI percentile.
†$P < .05$, boys compared with girls.
‡$P < .05$, left compared with right.
§$P < .05$, baseline compared with cold exposed.

Table III. Relationship between supraclavicular skin temperature measured by infrared thermography and food consumption score in healthy volunteer boys and girls aged 8-11 years (n = 36)

	Boys						Girls					
	Left			Right			Left			Right		
Correlations with consumption score*	Before	After	Change	Before	After	Change	Before	After	Change	Before	After	Change
Carbohydrate	−0.05	−0.02	0.10	−0.09	−0.09	0.00	0.21	0.16	−0.19	0.20	0.20	0.01
Dairy	−0.23	−0.25	−0.09	−0.29	−0.31	−0.04	0.11	0.13	0.06	0.09	0.16	0.19
Fruit	−0.33	−0.25	0.21	−0.25	−0.26	−0.01	−0.07	−0.07	0.00	−0.09	−0.08	0.03
Protein	−0.02	−0.08	−0.19	0.07	−0.03	−0.31	0.48[†,‡]	0.48[†,‡]	0.00	0.47[†,‡]	0.51[†,‡]	0.09
Savory	−0.19	−0.26	−0.23	−0.20	−0.27	−0.24	0.32	0.28	−0.12	0.39	0.39	−0.01
Sweet	−0.39	−0.42	−0.12	−0.43	−0.46	−0.07	−0.19	−0.15	0.13	−0.12	−0.08	0.14
Vegetable	0.11	0.13	0.06	−0.01	0.03	0.14	0.53[†,‡]	0.46[†]	−0.23	0.52[†,‡]	0.48[†,‡]	−0.13

*Pearson product-moment coefficient.
†$P < .05$.
‡Statistical significance after adjustment for multiple comparisons.

for the main effect of sedentary behavior on the left or right supraclavicular region temperature at baseline, or after cold exposure (baseline, right supraclavicular region temperature mean difference, −0.25°C [95% CI, −0.54 to 0.05°C; $P = .09$]; left supraclavicular region temperature mean difference, −0.12°C [95% CI, −0.43 to 0.19°C; $P = .44$]; after cold exposure, right supraclavicular region temperature mean difference, −0.18°C [95% CI, −0.46 to 0.10°C; $P = .19$]; left supraclavicular region temperature mean difference, −0.10°C [95% CI, −0.39 to 0.22°C; $P = .58$]).

Fifty-three percent of children were reported to be picky eaters by their parents. There was no significant difference between the eating behavior of girls or boys (Table I). A 2-way ANCOVA was conducted to examine the effects of sex and picky eating behavior on supraclavicular region temperature, while adjusting for the effect of BMI percentile, and there was no statistically significant 2-way interaction between sex and picky eating behavior while controlling for BMI percentile (Table V; available at www.jpeds.com).

Therefore, an analysis of the main effects of picky eating behavior and sex was performed. The main effect of eating behavior showed no statistically significant difference in unweighted marginal adjusted means of the left or right supraclavicular region temperature at baseline or after cold exposure (baseline, right supraclavicular region temperature mean difference, 0.04°C [95% CI, −0.26 to 0.34°C; $P = .79$]; left supraclavicular region temperature mean difference, −0.07°C [95% CI, −0.38 to 0.23°C; $P = .63$]; after cold exposure, right supraclavicular region temperature mean difference, 0.01°C [95% CI, −0.27 to 0.29°C; $P = .93$]; left supraclavicular region temperature mean difference, −0.01°C [95% CI, −0.31 to 0.29°C; $P = .96$]).

Discussion

We found a sexual dimorphism in the skin temperature overlying supraclavicular BAT in young children, which may be related to dietary intake. Boys exhibit higher BAT activity under resting and cold-stimulated conditions than girls of a similar age and BMI, indicating that boys may have not only higher basal BAT activity under free-living conditions, but also that BAT that is more responsive to cold stimulation.

Previous investigations of the impact of sex on BAT in healthy young children are currently limited, with the majority of studies confined to clinical imaging in the context of pediatric malignancy. Furthermore, because the purpose of such scanning is to determine disease recurrence/progression, these scans are undertaken under environmental conditions designed to minimize BAT uptake of radiolabeled fluorodeoxyglucose (FDG; ie, warm room temperatures) and do not measure BAT activity in response to physiological BAT substrates. Despite these limitations, a small number of studies support our findings. Gilsanz et al found no sex-specific differences in the numbers defined as BAT positive on PET-CT (57% girls vs 60% boys); however, multiple regression analysis identified an independent effect of sex on BAT volume after adjustment for pubertal stage, BMI, season, and exposure to previous glucocorticoid treatment.[14] Chalfant et al identified BAT in 65% of boys and only 50% of girls (using PET-CT after successfully treated malignancy) and, although not statistically significant, their study was not specifically powered to explore sex differences.[27]

Similarly, Drubach et al reported no difference in overall BAT activity in boys and girls on PET-CT.[26] However, when stratified by age group, median BAT activity was 2.4 times higher in boys than girls aged between 11 and 13 years.[26] Deng et al identified sex as a significant covariate of the magnetic resonance imaging (MRI) properties of BAT in 28 young healthy children aged 9-15 years, reporting increased markers of tissue perfusion (apparent tissue diffusion coefficient and perfusion coefficient) on diffusion-weighted imaging, and a higher T2* using Dixon MRI findings, suggestive of higher BAT activity in boys in this age group.[25] Even fewer studies have directly examined childhood BAT histologically, but those that have report either no sex-specific differences, or did not look for them.[10,11]

Differences between prepubertal girls and boys that are contrary to our findings have been reported.[30] However, these differences were principally identified when "area" of the supraclavicular region was used as a thermal index. This measure, defined as the number of pixels over an arbitrary threshold of 35.5°C, has yet to be validated against other assessments of BAT, such as PET-CT in the same way as supraclavicular region temperature.

The children taking part in this study were between the ages of 8.5 and 11.8 years. The UK median age of pubertal onset is 11.3 and 11.6 years for girls and boys respectively, meaning our study population may be a heterogeneous group in terms of pubertal stage.[38] It is, therefore, likely that they exhibited a wide range of gonadotrophin and sex steroid hormones that could explain, in part, variation in basal and cold-stimulated supraclavicular region temperature. Given that our study was undertaken in the primary school environment, physical assessment of pubertal stage was not considered appropriate. Future study under laboratory conditions utilizing self-reported pubertal stage in combination with noninvasive measures of sex steroid hormones (eg, saliva or urinary assays) presents a practical and ethical solution to the assessment of supraclavicular region temperature in relation to pubertal status for future studies.

Our univariate analyses suggest that BAT thermogenesis may also be influenced by dietary intake in a sex-specific manner. In girls, greater vegetable and protein consumption was associated with a lower supraclavicular region temperature (lower BAT activity). However, the sample size of our study was limited and it was underpowered to detect significant relationships between supraclavicular region temperature and food consumption after correction for multiple testing. Parental reports of dietary intake may be subject to bias. Hours of screen time are commonly used as a simple assessment of sedentary behavior, but may falsely classify some children as active, and can also be associated with dietary intake.[39,40] The use of accelerometry in future studies could provide a comprehensive assessment of movement duration and intensity.

The insulative effect of overlying subcutaneous adipose tissue (SCAT) has not been quantified. Gatidis et al suggest that SCAT significantly impacts supraclavicular region temperature; however, their measurements were defined as the minimal distance between the vascular compartment and the skin of the neck (rather than the white fat layer that lies immediately below the dermis).[41] Biopsy of adipose tissue surrounding the supraclavicular vasculature clearly demonstrates UCP1, indicative of capacity for thermogenesis.[42] Therefore, the assumption that this layer is purely insulative is too simplistic. Because the white fat layer immediately below the skin in the posterior triangle of the skin is minimal in healthy subjects in our studies, we have been unable to obtain reproducible and robust measures with either ultrasound examination or MRI. We have, however, identified that the relationship between supraclavicular region temperature and BMI persists in a nonobese group after adjustment for SCAT in close proximity to the supraclavicular region (dorsal aspect at T1; unpublished data, L. Robinson, M.E. Symonds, and H. Budge, 2019). The dynamic response of supraclavicular region temperature correlates well with FDG uptake in BAT on PET-CT in a nonobese adult cohort with proven FDG detected BAT, the children in this study were similarly nonobese, and all had a BMI percentile of the 85th percentile or less.[15] These findings suggest that the insulative effect of SCAT is minimal, in a nonobese population at least.

Given the contribution of BAT to energy balance and metabolic health, further exploration of these findings will provide a better understanding of how BAT may be activated, and recruited, in early life. This study helps to delineate how BAT dysfunction may predispose to childhood obesity. ■

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Data Statement

Data sharing statement available at www.jpeds.com.

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Table IV. Means (SEM) for left and right supraclavicular skin temperature, unadjusted and adjusted for BMI percentile, in sedentary and active healthy children at baseline, and after 5 minutes cold exposure (n = 36)

	Boys Left T_{SCR} (°C) Sedentary (n = 10)	Boys Left T_{SCR} (°C) Active (n = 6)	Girls Left T_{SCR} (°C) Sedentary (n = 12)	Girls Left T_{SCR} (°C) Active (n = 8)	Boys Right T_{SCR} (°C) Sedentary (n = 10)	Boys Right T_{SCR} (°C) Active (n = 6)	Girls Right T_{SCR} (°C) Sedentary (n = 12)	Girls Right T_{SCR} (°C) Active (n = 8)
Baseline T_{SCR}								
Mean	35.82	35.97	35.50	35.44	35.88	36.26	35.64	35.60
SE	0.20	0.11	0.20	0.13	0.20	0.11	0.17	0.18
Mean adjusted	35.73	35.93	35.51	35.56	35.79	36.22	35.66	35.72
SE	0.14	0.18	0.13	0.16	0.13	0.17	0.12	0.15
Cold exposed T_{SCR}								
Mean	36.06	36.06	35.51	35.51	36.11	36.27	35.61	35.65
SE	0.22	0.09	0.20	0.13	0.22	0.08	0.17	0.16
Mean adjusted	35.96	36.01	35.53	35.64	36.01	36.23	35.63	35.78
SE	0.14	0.18	0.12	0.15	0.13	0.16	0.11	0.14

ANCOVA: baseline left supraclavicular region temperature, F = 0.25, partial η^2 = 0.008, P = .62; right supraclavicular region temperature, F = 1.66, partial η^2 = 0.051, P = .28; cold stimulated left supraclavicular region temperature, F = 0.04, partial η^2 = 0.001, P = .84; cold stimulated right supraclavicular region temperature, F = 0.06, partial η^2 = 0.002, P = .81.

Table V. Means (SEM) for the left and right supraclavicular skin temperature, unadjusted and adjusted for BMI percentile, in children classified as picky or nonpicky eaters at baseline and after 5 minutes of cold exposure (n = 36)

	Boys left T_{SCR} (°C) Picky (n = 8)	Boys left T_{SCR} (°C) Not picky (n = 8)	Girls left T_{SCR} (°C) Picky (n = 11)	Girls left T_{SCR} (°C) Not picky (n = 9)	Boys right T_{SCR} (°C) Picky (n = 8)	Boys right T_{SCR} (°C) Not picky (n = 8)	Girls right T_{SCR} (°C) Picky (n = 11)	Girls right T_{SCR} (°C) Not picky (n = 9)
Baseline T_{SCR}								
Mean	35.96	35.79	35.49	35.46	36.07	35.98	35.57	35.69
SE	0.19	0.19	0.16	0.20	0.22	0.18	0.17	0.17
Mean adjusted	35.82	35.80	35.59	35.46	35.93	35.98	35.67	35.70
SE	0.16	0.16	0.14	0.15	0.16	0.16	0.13	0.15
Cold exposed T_{SCR}								
Mean	36.12	36.00	35.49	35.53	36.27	36.07	35.55	35.71
SE	0.20	0.19	0.16	0.21	0.22	0.17	0.16	0.18
Mean adjusted	35.96	36.00	35.60	35.54	36.12	36.08	35.66	35.72
SE	0.16	0.15	0.13	0.14	0.15	0.14	0.12	0.14

ANCOVA: baseline left supraclavicular region temperature, F = 0.11, partial η^2 = 0.004, P = .77; right supraclavicular region temperature, F = 0.01, partial η^2 = 0.0004, P = .92; cold-stimulated left supraclavicular region temperature, F = 0.12, partial η^2 = 0.004, P = .73; cold stimulated right supraclavicular region temperature, F = 0.13, partial η^2 = 0.004, P = .72.