Thermoregulatory and perceptual responses of lean and obese fit and unfit girls exercising in the heat

Carolina de Ávila Rodrigues, Gabriela Tomedi Leites, Flavia Meyer

Universidade Federal do Rio Grande do Sul (UFRGS), Escola de Educação Física, Fisioterapia e Dança, Porto Alegre, RS, Brazil

Received 22 September 2018; accepted 21 December 2018
Available online 18 April 2019

Abstract
Objective: To verify the thermoregulatory and perceptual responses of obese and lean girls, either fit or unfit, exercising in the heat at a similar rate of metabolic heat production per unit body mass.

Methods: A total of 34 pubescent girls were allocated in four groups: 12 obese fit, 9 obese unfit, 5 lean fit, and 8 lean unfit. The obese groups (13.2 ± 1.4 years, 40.5% ± 5.8% fat by DXA) differed in their aerobic fitness (VO2peak 76.0 ± 8.1 vs. 56.6 ± 5.8 mL.kg muscle mass−1.min−1), as well as the lean groups (13.1 ± 1.6 years, 24.0% ± 4.8% fat) (VO2peak 74.5 ± 2.9 vs. 56.2 ± 5.0 mL.kg muscle mass−1.min−1). Girls cycled two bouts of 2 min with a 10 min rest in between, at ∼5.4 W.kg−1 in the heat (36 °C and 40% relative humidity) and they were kept euhydrated. Rectal and skin temperatures and heart rate were measured every 5 min. Perceptual responses were evaluated throughout the exercise.

Results: Initial rectal temperature was higher in the obese subjects compared to the lean subjects (37.5 ± 0.3 and 37.2 ± 0.3 °C). No difference was observed among the girls whom were obese (eight fit or unfit) and lean (also fit or unfit) throughout the exercise in rectal temperature (37.6 ± 0.2, 37.5 ± 0.3, 37.5 ± 0.3, 37.4 ± 0.3 °C, respectively), skin temperature (34.8 ± 0.8, 35.1 ± 1.0, 34.4 ± 0.9, 35.2 ± 0.9 °C), and heart rate (128 ± 18; 118 ± 12, 130 ± 16, 119 ± 16 beats min−1). No differences were observed in perceptual responses among groups.

Conclusion: Regardless of the adiposity or aerobic fitness, pubescent girls had similar thermoregulatory and perceptual responses while cycling in the heat at similar metabolic heat production.

© 2019 Sociedade Brasileira de Pediatria. Published by Elsevier Editora Ltda. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Please cite this article as: Rodrigues CÁ, Leites GT, Meyer F. Thermoregulatory and perceptual responses of lean and obese fit and unfit girls exercising in the heat. J Pediatr (Rio J). 2020;96:464–71.

* Corresponding author.
E-mail: gabitomedi@yahoo.com.br (G.T. Leites).

https://doi.org/10.1016/j.jped.2018.12.011
0021-7557/© 2019 Sociedade Brasileira de Pediatria. Published by Elsevier Editora Ltda. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Respostas termorregulatórias e perceptivas de meninas magras e obesas com alta e baixa aptidão aeróbica exercitando-se no calor

Resumo

Objetivo: Verificar as respostas termorregulatórias e perceptivas de meninas obesas e magras, com alta e baixa aptidão aerobic, exercitando-se no calor com produção metabólica de calor similar por massa corporal.

Métodos: Um total de 34 meninas púberes foram alocadas em quatro grupos: 12 obesas com alta aptidão aeróbica, 9 obesas com baixa aptidão aeróbica, 5 magras com alta aptidão aeróbica e 8 magras com baixa aptidão aeróbica. Os grupos obesos (13,2 ± 1,4 anos, 40,5% ± 5,8% de gordura por DXA) diferiram em sua aptidão aeróbica (VO₂peak, 76,0 ± 8,1 vs. 56,6 ± 5,8 mL.kg de massa muscular⁻¹.min⁻¹), bem como os grupos magros (13,1 ± 1,6 anos, 24,0% ± 4,8% de gordura) (VO₂peak 74,5 ± 2,9 vs. 56,2 ± 5,0 mL.kg de massa muscular⁻¹.min⁻¹). As meninas pediram duas sessões de 25 minutos com descanso de 10 minutos entre as sessões, a ~5,4 W.kg⁻¹ no calor (36 °C e 40% de umidade relativa) e foram mantidas hidratadas. As temperaturas retal e cutânea e a frequência cardíaca foram medidas a cada 5 minutos. As respostas perceptivas foram avaliadas durante o exercício.

Resultados: A temperatura retal inicial foi maior nas meninas obesas em comparação com as magras (37,5 ± 0,3 e 37,2 ± 0,3 °C). Não houve diferença entre as meninas obesas (com alta aptidão aeróbica ou não) e magras (também com alta aptidão aeróbica ou não) durante todo o exercício em relação à temperatura retal (37,6 ± 0,2; 37,5 ± 0,3; 37,4 ± 0,3 °C; respectivamente), temperatura da pele (34,8 ± 0,8; 35,1 ± 1,0; 34,4 ± 0,9; 35,2 ± 0,9 °C), e frequência cardíaca (128 ± 18; 118 ± 12, 130 ± 16, 119 ± 16 batimentos.min⁻¹). Não foram observadas diferenças nas respostas perceptivas entre os grupos.

Conclusão: Independente da adiposidade ou do condicionamento aeróbico, as meninas púberes tiveram respostas termorregulatórias e perceptivas semelhantes, enquanto pedalavam no calor com uma produção metabólica de calor similar.

© 2019 Sociedade Brasileira de Pediatria. Publicado por Elsevier Editora Ltda. Este é um artigo Open Access sob uma licença CC BY-NC-ND (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Introduction

Few studies have shown thermoregulatory and perceptual disadvantages of obese compared to lean children during exercise in the heat, although obesity has been pointed as a risk factor for exertional heat illnesses. Physical inactivity and poor aerobic fitness – generally associated with obesity – may also impair thermoregulatory responses, representing an aggravating condition when prescribing exercise in warm conditions.

Depending on girls’ aerobic fitness, there may be thermoregulatory and perceptual differences within those who are lean and obese. Aerobic exercise is often recommended for weight management, but adherence may be impaired if girls experience discomfort. In addition to health and safety considerations, the recommended exercise should be enjoyable. Currently, there is evidence about the impact of fitness associated with adiposity on physiological and perceptual responses during moderate prolonged exercise in the heat.

Furthermore, no confirmation exists that obese teens respond with greater increase in core temperature compared to their lean peers during exercise in the heat. Conflictingly, Leites et al. showed that girls who are obese had a smaller increase in rectal temperature (T Re) during exercise in hot conditions compared to the lean ones; however, in boys the responses were similar.

Core temperature can be different between males and females, which could be due to hormones, as estrogen plays a role in thermoregulation and sweating responses. Another explanation for conflicting results may be related to the traditional method of setting the exercise intensity protocol load by a certain % of the individual’s peak oxygen consumption (VO₂peak). As suggested, such an approach may induce greater metabolic heat production (H P) in the lean compared to the obese girls, explaining their greater T Re increase.

Previous studies compared heterogeneous body mass groups using a given % VO₂peak or an absolute walking speed, which could result in different H P per body unit. A study that compared two groups of adults matched by body mass and body surface area (BSA), with distinct VO₂peak (~60 vs. 40.3 mL.kg⁻¹.min⁻¹) and % body fat (~12% vs. 22%), showed that exercise at a given absolute H P, but not necessarily at a similar % VO₂peak, resulted in a similar core temperature increase. Setting the exercise intensity by H P per body unit has been considered a better method to compare groups of heterogeneous body size. In youths, there are no studies that have aimed to examine thermoregulatory responses to exercise that considered both aerobic fitness and adiposity.
Perceptual responses may also interfere with exercise tolerance and program adherence under heat conditions. Among active prepubescent girls, thermal comfort was similar between the lean and obese groups; however, the lean girls reported greater irritability during 30 min of cycling in the heat. Obese pubertal boys who were active reported a higher heat sensation compared to their active lean peers while cycling for 30 min at similar % VO$_{2peak}$ in the heat. Boys whom are obese (9–12 years old) showed greater perceived effort (2–3 points on Borg scale) compared to the lean boys at similar absolute exercise intensity in the heat. None of the above mentioned studies had considered aerobic fitness differences between groups.

Despite the consensus that increasing physical activity is a key aspect in the management of pediatric obesity, exercise appears to be a concern for unfit girls when performed in a warm climate. Such external conditions may serve as another excuse to limit even mild-to-moderate physical activities in sedentary obese girls. Clarification about the effect of obesity and fitness in youth during exercise in the heat will help clinicians and health professionals to recommend safe and enjoyable exercise to optimize body composition, aerobic fitness, and metabolic health. The purpose of this study was to verify thermoregulatory and perceptive responses of obese and lean girls, both fit and unfit, during exercise in the heat at a given $H_p$.

Methods

Subjects

Thirty-four girls were studied, divided into four groups according to adiposity (obese and lean) and aerobic fitness (fit and unfit), resulting in 21 obese (12 fit and nine unfit) and 13 lean (5 fit and 8 unfit). Body fat was obtained by dual energy X-Ray absorptiometry (DXA) to classify the girls as lean or obese (<32 or ≥32% body fat), and VO$_{2peak}$ was evaluated to classify them as fit or unfit (≥69 or <64 mL.kg total muscle mass$^{-1}$.min$^{-1}$). For fitness, a VO$_{2peak}$ cut-off point was set from the Gaussian curve of the girls VO$_{2peak}$ measurements. A Standard Deviation (SD) of ±0.25 was adopted, ensuring a mean of 20 mL.kg total muscle mass$^{-1}$.min$^{-1}$ difference between groups.

Girls and their parents/guardians were informed about procedures and provided written informed assent and consent to participate in the study, which was approved by the University Research Ethics Board.

Girls came to the laboratory for a preliminary and an experimental session, two to seven days apart, between March and May, which are predominantly warm months in Southern Brazil.

Preliminary session

Health condition was assessed by a questionnaire, which showed that the girls were healthy and not taking medications. Body mass and height were measured, and Body Mass Index (BMI) and BSA$^5$ were calculated. Biological maturation was determined using self-assessed Tanner staging.$^{16}$ Body composition was measured by using DXA (Lunar GE Pencil Bin, SmartScan pediatric program; GE Medical Systems Lunar – Diegem, Belgium).

To determine VO$_{2peak}$, an incremental exercise test was performed in a thermoneutral room (~24°C) on a cycle ergometer (Ergo Fit, model 167 – Toledo, Spain) using the McMaster All-Out Progressive Continuous Cycling protocol.$^3$Expired O$_2$ and CO$_2$ were continuously monitored using a calibrated metabolic cart (O$_2$ and CO$_2$ analyzer; Iniramed, model VO2000 – Porto Alegre, Brazil). The test was terminated if one of the following criteria was achieved: (1) inability to maintain a cycling cadence >60 rpm, despite strong verbal encouragement; (2) Heart Rate (HR) >95% of $HR_{max}$; (3) RPE >19; or (4) Respiratory Exchange Ratio (RER) >1.0. VO$_{2peak}$ was considered as the highest VO$_2$ value. VO$_{2peak}$ was corrected for total muscle mass to avoid a confounding effect of fat mass and total body mass.$^{18}$

At the end of this session, girls were instructed to refrain from any strenuous exercise and not to change their eating habits 24 h prior to the experimental trial, which happened 2–3 h after a major meal.

Experimental trial

Upon arrival to the laboratory, hydration status was verified from a sample of urine by examining the color.$^{19}$ This was followed by body mass measurement and baseline $T_{re}$, skin temperatures ($T_{sk}$), and HR. $T_{re}$ was measured using a flexible thermometer (Physitemp Instruments, Inc. Ret-1 model – Clifton, NJ, United States) inserted 10–12 cm beyond the anal sphincter. $T_{sk}$ at four sites were measured using skin thermometers (Physitemp Instruments, Inc., SST-1 model – Clifton, NJ, United States), placed on the arm ($T_a$), chest ($T_c$), upper back ($T_u$), and thigh ($T_t$). Mean $T_{sk}$ was calculated according to the equation: $(0.3 \cdot T_a) + (0.3 \cdot T_c) + (0.2 \cdot T_u) + (0.2 \cdot T_t)$.

The girls received standardized instructions on how to answer four perceptual scales: (1) RPE,$^{20}$ (2) Thermal sensation (9 point scale from “very cold” to “very hot”),$^{21}$ (3) Thermal comfort (6 point scale from “very comfortable” to “very uncomfortable”), and (4) Irritability (6 point scale from “nothing” to “very intense”).

Prior to exercise, the girls rested in a seated position for five min in the climatic chamber (Russel Technical Products – Netherlands, 13 m$^2$) set at 36°C and 40% relative humidity, resulting in a humidex factor of 44°C. The girls exercised wearing a top, athletic shorts, and shoes.

The exercise cycling protocol consisted of two 25 min bouts at a fixed $H_p$ per unit body mass (~5.4 W.kg$^{-1}$) with a 10 min rest between bouts of cycling. VO$_2$ and VCO$_2$ were measured during the bouts for at least 10 min. $T_{re}$, $T_{sk}$, HR, and perceptual scores were recorded every 5 min during exercise. Total body temperature ($T_{body}$) was calculated as the following equation$^{22}$: $T_{body} = (0.8 \cdot T_{re}) + (0.2 \cdot T_{sk})$

To keep euhydrated, each girl ingested a water volume at rest (between bouts) equivalent to her individual loss that was calculated from the body mass difference relative to her initial value. After the whole session, the girls dried their skin and body mass was evaluated with bare feet to calculate the sweat volume: $\Delta$body mass$\times$volume of water intake.
Table 1  Physical and physiological characteristics of obese and lean girls.

|                                | Obese                        | Lean                         | p-Total | p-Group |
|--------------------------------|------------------------------|------------------------------|---------|---------|
|                                | Total (21) | Fit (12) | Unfit (9) | Total (13) | Fit (5) | Unfit (8) |         |         |
| Age (years)                    | 13.2 ± 1.4 | 13.3 ± 1.5 | 13.1 ± 1.4 | 13.1 ± 1.6 | 13.0 ± 1.6 | 13.2 ± 1.7 | 0.91    | 0.97    |
| Body mass (kg)                 | 60.8 ± 13.7<sup>a</sup> | 58.6 ± 12.9 | 63.6 ± 15.0<sup>c</sup> | 44.1 ± 6.5<sup>c</sup> | 44.7 ± 8.0<sup> c</sup> | 43.8 ± 5.9<sup> c</sup> | <0.01   | 0.03    |
| Body height (cm)               | 158 ± 0.1  | 158 ± 0.1  | 158 ± 0.0  | 156 ± 0.1  | 156 ± 0.1  | 156 ± 0.0  | 0.50    | 0.95    |
| Body surface area (m²)         | 1.6 ± 0.1<sup>a</sup> | 1.5 ± 0.1  | 1.6 ± 0.2<sup>c</sup> | 1.4 ± 0.1<sup> a</sup> | 1.4 ± 0.1  | 1.3 ± 0.1<sup> c</sup> | <0.01   | 0.00    |
| Total muscle mass (kg)         | 33.3 ± 5.8 | 31.8 ± 3.8 | 35.5 ± 7.4 | 30.9 ± 3.4 | 29.9 ± 4.3  | 31.5 ± 2.8  | 0.18    | 0.18    |
| Lower limb muscle mass (kg)    | 11.7 ± 2.1 | 11.2 ± 1.3 | 12.5 ± 2.8 | 10.5 ± 1.4 | 9.9 ± 1.6  | 11.0 ± 1.1  | 0.08    | 0.10    |
| Percentage body fat            | 40.5 ± 5.8 | 41.0 ± 6.8<sup>c</sup> | 39.9 ± 4.6<sup>c</sup> | 24.0 ± 4.8 | 25.1 ± 4.6  | 23.3 ± 5.1<sup>c</sup> | <0.01   | <0.01   |
| Aerobic fitness                |                |                |            |                |                |            |         |         |
| VO<sub>peak</sub> (mL.min<sup>−1</sup>) | 2243 ± 456 | 2408 ± 294<sup>a</sup> | 2023 ± 553 | 1935 ± 347 | 2230 ± 329  | 1750 ± 209<sup>a</sup> | 0.04    | 0.04    |
| VO<sub>peak</sub> (mL.kg<sup>−1</sup>.min<sup>−1</sup>) | 37.7 ± 7.8<sup>b</sup> | 42.0 ± 6.7<sup>b</sup> | 31.9 ± 5.4<sup>b</sup>,<sup>f</sup> | 44.1 ± 6.9<sup>a</sup> | 50.3 ± 4.3<sup>b</sup>,<sup>f</sup> | 40.3 ± 5.3<sup>b</sup>,<sup>f</sup> | 0.02    | <0.01   |
| VO<sub>peak</sub> (mL.kg total muscle mass<sup>−1</sup>.min<sup>−1</sup>) | 67.7 ± 12.1 | 76.0 ± 8.1<sup>d</sup> | 56.6 ± 5.8 | 63.2 ± 10.2 | 74.5 ± 2.9<sup>d</sup> | 56.2 ± 5.0<sup>d</sup> | 0.27    | <0.01   |
| Heart rate<sub>max</sub> (beats min<sup>−1</sup>) | 180 ± 13 | 181 ± 13 | 178 ± 16 | 180 ± 12 | 187 ± 7  | 175 ± 12  | 0.48    | 0.98    |
| Biological maturation           |                |                |            |                |                |            |         |         |
| Tanner stage                    | 4              | 4              | 4          | 4              | 4              | 3          | 0.10    | 0.65    |

<sup>a</sup> Obese > lean.
<sup>b</sup> Fit > Unfit.
<sup>c</sup> Obese unfit > Lean fit and lean unfit.
<sup>d</sup> Obese fit > Lean fit and lean unfit.
<sup>e</sup> Obese fit > Lean unfit.
<sup>f</sup> Obese unfit < Lean fit and lean unfit.

p-total, comparison between total obese and lean girls; p-group, comparison among groups (obese fit, obese unfit, lean fit, lean unfit).
Metabolic heat production

The rate of metabolic energy expenditure (M; W.m⁻²) was estimated using the average VO₂ (L.min⁻¹) and RER measured during exercise, calculated as:\(^24\):

\[
M = \frac{\left( \frac{60}{2.2} \right) \times e_f + \left( \frac{10.604}{4.9} \right) \times \text{BSA}}{1000};
\]

where \(e_f\) is the caloric equivalent per liter of O₂ for carbohydrate oxidation (21.13 kJ), and \(e_f\) for fat oxidation (19.62 kJ). \(H_p\) (W.m⁻²) was calculated as the difference between \(M\) and the external work rate (W).

\[
H_p = M - W
\]

Statistical analyses

The Shapiro-Wilk test was applied to verify data normality and Levene’s test was used to determine the homogeneity of variance. Student t-test was used to compare groups (obese vs. lean) and characteristics (i.e., weight, height, BSA, % body fat, fat mass, total muscle mass, aerobic fitness, and HRmax). To analyze exercise intensity, urine color, sweat volume, and water balance by aerobic fitness and adiposity, one-way ANOVAs were conducted. Bonferroni post hoc analyses were used to examine significant interactions. The Generalized Estimated Equation (GEE) was used to compare groups (obese fit, obese unfit, lean fit, and lean unfit) over time (\(T_{re}, T_{sk}, HR\), RPE, irritability, thermal sensation, and comfort). Pearson’s correlation coefficient was used for the body fat and \(T_{re}\). Data are expressed as mean ± SD. Statistical significance was set at \(p < 0.05\), and analysis were performed using SPSS v.18.0 (SPSS Inc – Chicago, IL, United States).

### Results

Table 1 shows the physical characteristics by group. Obese groups were heavier, with greater BSA, BMI, body fat, muscle mass, and \(\text{VO}_2\text{peak}\); however, they presented lower \(\text{VO}_2\text{peak}\) by body mass. \(\text{VO}_2\text{peak}\) by total muscle mass was lower in the unfit compared to the fit girls \(p < 0.001\).

During exercise, obese fit girls had a higher absolute \(H_p\) compared to lean unfit girls \((313 ± 62 vs. 232 ± 48 W; p = 0.02)\). \(H_p\) per unit body mass (W.kg⁻¹) was similar among obese and lean subjects, both fit and unfit. Obese and lean girls cycled at similar \(H_p\) (5.4 W.kg⁻¹, \(p = 0.10\)) and mean workload during exercise was 30 and 32 W, respectively (Table 2).

Participants arrived with similar hydration levels according to urine color (obese fit, obese unfit, lean fit, and lean unfit: 4±2, 4±2, 4±1, and 4±1, respectively). Table 3 shows the sweating response and body hydration status of the groups. Total sweat volume was similar among groups \((p = 0.30)\), even when corrected by BSA \((p = 0.5)\). Body water balance at the end of the experiment was similar among groups, resulting in a low deficit of 0.4±0.2 and 0.5±0.3 L, in the obese and lean groups, respectively.

**Fig. 1** depicts \(T_{re}, T_{sk}, T_{body}, \text{ and HR over the two 25 min bouts of exercise.} \(T_{re}\) response was similar between lean and obese for both the fit and unfit groups during exercise. No difference was observed among the four groups throughout the exercise in regional \(T_{sk}\) for the back, chest, arm, and thigh: 34.8±0.8 obese fit; 35.1±1.0 obese unfit; 34.4±0.9 lean fit; and 35.2±0.9 °C lean unfit, and \(T_{body}\): 37.0±0.2 obese fit, 37.0±0.4 obese unfit, 36.8±0.3 lean fit, and 36.9±0.3 °C lean unfit. HR was similar between obese and lean girls at the beginning of exercise \((101±14 and 99±12 beats min⁻¹)\) and it increased similarly among the four groups (obese fit, obese unfit, lean fit, and lean unfit).

### Table 2  Average metabolic heat production \((H_p)\) and workload values during exercise in the heat in obese and lean girls.

|                | Obese       | Lean       | p-Total | p-Group |
|----------------|-------------|------------|---------|---------|
|                | Total (21)  | Fit (12)   | Unfit (9)|         |         |
| \(H_p\) (W)    | 304 ± 60    | 313 ± 62   | 292 ± 58|         |         |
| \(H_p\) (W.m⁻²)| 190 ± 38    | 199 ± 42   | 178 ± 30|         |         |
| \(H_p\) (W.kg⁻¹)| 5.2 ± 1.2  | 5.5 ± 1.4  | 4.7 ± 0.9|         |         |
| Workload (W)   | 30 ± 12     | 31 ± 12    | 28 ± 13 |         |         |
| % \(\text{VO}_2\text{max}\) | 44.1 ± 7.5 | 41.5 ± 5.5 | 57.7 ± 8.6 |         |         |

\(a\) Obese > Lean.

\(b\) Obese fit > Lean unfit.

### Table 3  Sweating responses and total water balance during exercise in the heat in obese and lean girls.

|                | Obese       | Lean       | p Total | p Group |
|----------------|-------------|------------|---------|---------|
|                | Total (21)  | Fit (12)   | Unfit (9)|         |         |
| Sweat volume (mL) | 361 ± 189  | 345 ± 121  | 454 ± 269|         |         |
| Sweat volume/BSA (mL.m⁻²) | 212 ± 115  | 221 ± 85   | 199 ± 152|         |         |
| Total water balance | -0.4 ± 0.2 | -0.3 ± 0.2 | -0.3 ± 0.2 | -0.5 ± 0.3 | -0.3 ± 0.3 | -0.5 ± 0.2 | 0.4 | 0.4 |

BSA, body surface area.
Discussion

The main finding of this study is that thermoregulatory and perceptual responses were similar independent of the group during the 25 min cycling bouts at similar \( H_p \) per unit body mass in the heat. This suggests that when exercising at a moderately high intensity in exercise/heat conditions, obese and uninfit girls did not differ regarding body temperatures and sweating responses compared to their lean and fit peers. Their perceived exertional, thermal sensation, and comfort responses throughout exercise were also similar among groups.

Although fit obese girls started exercise at a higher \( T_r \) than fit lean girls, responses were similar among groups during exercise. Compared to the lean, obese children may present greater absolute resting metabolic rate and metabolic heat production due to differences in body composition.\(^6,21\) In addition, since fat mass has a specific heat that is approximately half of that of fat-free mass, it may result in greater heat storage in the obese. All girls were naturally heat acclimatized, and previous hydration and resting conditions were controlled to eliminate these factors as responsible for baseline value differences.

A few studies have verified thermoregulatory responses in obese children\(^1,10\) and adolescents\(^1,2,13\) during exercise in the heat; however, only two included females.\(^8,26\)

There are inconsistent results about the influence of body fat on thermoregulation during exercise in the heat. Lean girls had a greater \( T_r \) increase toward the end of a 30 min exercise session, and the authors\(^8\) suggested that it could be due to the greater muscle mass compared to that of the obese group. In the present study, the absolute fat free mass was similar between groups (33.3 vs. 30.9 kg), although the % fat was almost twice that of the lean girls (40.5 vs. 24.0). Such similar absolute muscle mass of the obese and lean girls could explain their similar \( T_r \) responses. The present study’s cycling protocol properly achieved the goal of having the girls exercising at similar \( H_p \). Lelies et al.\(^6,16\) showed that lean girls completed the exercise-in-the-heat protocol with a mean \( T_r \) of 0.2°C higher than the obese ones. It is possible that this difference occurred due to differences in exercise intensity (\% \( VO_2 \) vs. \( H_p \)). Recently, \( H_p \) by body mass method has been suggested\(^6\) to achieve similar heat storage when comparing thermoregulatory responses. Previous studies\(^11\) may have been biased by setting an exercise intensity protocol as a % \( VO_2\text{peak} \) and absolute workload to compare groups that vary in their physical fitness.

The present authors are unaware of any other study in adolescents that compared girls with distinct adiposity and aerobic fitness levels under an exercise protocol that is based on similar \( H_p \) and heat stress. The current study suggests the use of \( H_p \) by unit of body mass as an exercise protocol when comparing thermoregulatory responses between lean and obese girls, regardless of their aerobic fitness. Previous studies that compared groups (adults) with high and low adiposity,\(^9\) lean and obese,\(^11\) or with high and low aerobic fitness,\(^28\) found no \( T_s \) difference between groups. Therefore, it appears that adiposity and aerobic fitness do not influence \( T_r \) responses when a mild-to-moderate exercise intensity protocol is set by a given \( H_p \) per unit body mass.
The sweat volume showed great individual variability among the girls, as previously described, resulting in similar mean values among the lean/obese and fit/unit groups, even when corrected by BSA. This agrees with what was found in prepubertal girls and in pubertal boys.

Regardless of the adiposity levels, adolescents appear to produce similar volumes of sweat by BSA when exercising in the heat.

Few studies have evaluated perceptual responses of obese children and adolescents during exercise in heat. In the present study, all groups perceived the exercise as mild. They reported a low-to-moderate irritability, despite feeling a warm and uncomfortable ambient temperature. Differently, Leites et al. found that lean girls presented greater irritability during the exercise. Previous studies showed differences in RPE between lean and obese boys exercising in the heat. Obese boys also felt worse thermal comfort (8 vs. 5) compared to lean boys during exercise in the heat. It is possible that perceived responses are related to exercise intensity as well as gender. It is important to emphasize that exercise intensity was set to be low-to-moderate so that girls who are obese and sedentary could complete the exercise in the heat.

Regardless of the adiposity or aerobic fitness level, pubescent girls had similar thermoregulatory (£T_m, £Ta), sweating (sweat volume and water balance), and perceptual responses (RPE, irritability, thermal sensation, and comfort) while cycling under heat stress during 50 min at 5.4 W.kg⁻¹.

Conflicts of interest

The authors declare no conflicts of interest.

References

1. Dougherty KA, Chow M, Larry Kenney W. Critical environmental limits for exercising heat-acclimated lean and obese boys. Eur J Appl Physiol. 2010;108:779–89.
2. Sehl P, Leites G, Martins J, Meyer F. Responses of obese and non-obese boys cycling in the heat. Int J Sports Med. 2012;33:497–501.
3. Council on Sports Medicine and Fitness and Council on School Health, Bergeron MF, Devore C, Rice SG, American Academy of Pediatrics. Policy statement – climatic heat stress and exercising children and adolescents. Pediatrics. 2011;128:e741–7.
4. Dumith SC, Domingues MR, Gigante DP, Hallal PC, Menezes AM, Kohl HW. Prevalence and correlates of physical activity among adolescents from Southern Brazil. Rev Saúde Pública. 2010;44:457–67.
5. Bar-Or O, Rowland T. Pediatric exercise medicine: from physiologic principles to health care application, Champaign, IL. Hum Kinet. 2004.
6. Leites GT, Sehl PL, Cunha GS, Detoni Filho A, Meyer F. Responses of obese and lean girls exercising under heat and thermoneutral conditions. J Pediatr. 2013;162:1054–60.
7. Lei TH, Cotter JD, Schlader JZ, Stannard SR, Perry BG, Barnes MJ, et al. On exercise thermoregulation in females: interaction of endogenous and exogenous ovarian hormones. J Physiol. 2019;597:71–88.
8. Cramer MN, Jay O. Explained variance in the thermoregulatory responses to exercise: the independent roles of biophysical and fitness/fitness-related factors. J Appl Physiol. 2015;119:982–9.
9. Dervis S, Coombs GB, Chaseling GK, Filingeri D, Smoljancic J, Jay O. A comparison of thermoregulatory responses to exercise between mass-matched groups with large differences in body fat. J Appl Physiol Bethesda MD 1985. 2016;120:615–23.
10. Haymes EM, McCormick RJ, Buskirk ER. Heat tolerance of exercising lean and obese prepubertal boys. J Appl Physiol. 1979;39:457–61.
11. Jay O, Bain AR, Deren TM, Sacheli M, Cramer MN. Large differences in peak oxygen uptake do not independently alter changes in core temperature and sweating during exercise. AJP Regul Integr Comp Physiol. 2011;301:R832–41.
12. Leites GT, Cunha GS, Obeid J, Wilk B, Meyer F, Timmons BW. Thermoregulation in boys and men exercising at the same heat production per unit body mass. Eur J Appl Physiol. 2016;116:1411–9.
13. Dougherty KA, Chow M, Kenney WL. Responses of lean and obese boys to repeated summer exercise in the heat bouts. Med Sci Sports Exerc. 2009;41:279–89.
14. Lohman TG, Lohman TG. The use of skin fold to estimate body fatness on children and youth. J Phys Educ Recreat Dance. 1987;58:98–102.
15. Du Bois D, Du Bois EF. A formula to estimate the approximate surface area if height and weight be known. 1916. Nutrition. 1989;5:303–11 [discussion 312–3].
16. Tanner J. The development of the reproductive system. In: Growth at adolescence. Oxford: Blackwell Science; 1962.
17. Tanaka H, Monahan KD, Seals DR. Age-predicted maximal heart rate revisited. J Am Coll Cardiol. 2001;37:153–6.
18. Baker JS, Davies B. Quantification of active muscle mass during experimental exercise. J Appl Physiol (1985). 2006;100:1851–6.
19. Casa DJ, Armstrong LE, Hillman SK, Montain SJ, Reiff RV, Rich BS, et al. ‘National athletic trainers’ association position statement: fluid replacement for athletes. J Athl Train. 2000;35:212–24.
20. Borg G. Perceived exertion as an indicator of somatic stress. Scand. J Rehabil Med. 1970;2:92–8.
21. Arens E, Zhang H, Huizenga C. Partial- and whole-body thermal sensation and comfort – part I: uniform environmental conditions. J Therm Biol. 2006;31:53–9.
22. Hardy JD, Dubois EF. Regulation of heat loss from the human body. Proc Natl Acad Sci USA. 1937;23:624–31.
23. Inbar O, Morris N, Epstein Y, Gass G. Comparison of thermoregulatory responses to exercise in dry heat among prepubertal boys, young adults and older males. Exp Physiol. 2004;89:691–700.
24. Cena K, Clark JA. Politechnika Wrocławska. Bioengineering, thermal physiology, and comfort. Amsterdam; New York; New York: Elsevier Scientific Pub. Co.; Distribution for the U.S.A. and Canada, Elsevier/North-Holland; 1981. Available from: http://site.ebrary.com/id/10276475 [cited 02.08.16].
25. Heymsfield SB, Gallagher D, Kotlier DP, Wang Z, Allison DB, Heshka S. Body-size dependence of resting energy expenditure can be attributed to nonenergetic homogeneity of fat-free mass. Am J Physiol Endocrinol Metab. 2002;282:E132–8.
26. Fein JT, Haymes EM, Buskirk ER. Effects of daily and intermittent exposures on heat acclimation of women. Int J Biometeorol. 1975;19:41–52.
27. Limbaugh JD, Wimer GS, Long LH, Baird WH. Body fatness, body core temperature, and heat loss during moderate-intensity exercise. Aviat Space Environ Med. 2013;84:1153–8.
28. Cramer MN, Jay O. Selecting the correct exercise intensity for unbiased comparisons of thermoregulatory responses between groups of different mass and surface area. J Appl Physiol. 2014;116:1123–32.

29. Meyer F, Volterman KA, Timmons BW, Wilk B. Fluid balance and dehydration in the young athlete: assessment considerations and effects on health and performance. Am J Lifestyle Med. 2012;6:489–501.

30. Marnov B, Kostianev S, Turnovska T. Ventilatory efficiency and rate of perceived exertion in obese and non-obese children performing standardized exercise. Clin Physiol Funct Imaging. 2002;22:254–60.