Repeated-bout exercise in the heat in young athletes: physiological strain and perceptual responses

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Bergeron MF, Laird MD, Marinik EL, Brenner JS, Waller JL. Repeated-bout exercise in the heat in young athletes: physiological strain and perceptual responses. J Appl Physiol 106: 476–485, 2009. First published November 20, 2008; doi:10.1152/japplphysiol.00122.2008.—A short recovery period between same-day competitions is common practice in organized youth sports. We hypothesized that young athletes will experience an increase in physiological strain and perceptual discomfort during a second identical exercise bout in the heat, with 1 h (21°C) between bouts, even with ample hydration. Twenty-four athletes (6 boys and 6 girls: 12–13 yr old, 47.7 ± 8.3 kg; 6 boys and 6 girls: 16–17 yr old, 61.0 ± 8.6 kg) completed two 80-min intermittent exercise bouts (treadmill 60%, cycle 40% peak oxygen uptake) in the heat (33°C, 48.9 ± 6.1% relative humidity). Sweat loss during each bout was similar within each age group (12–13 yr old: bout 1, 943.6 ± 237.1 ml; bout 2, 955.5 ± 250.3 ml; 16–17 yr old: bout 1, 1,382.2 ± 480.7 ml; bout 2, 1,373.1 ± 472.2 ml). Area under the curve (AUC) was not statistically different (P > 0.05) between bouts for core body temperature (12–13 yr old: bout 1 peak, 38.6 ± 0.4°C; bout 2, 38.4 ± 0.2°C; 16–17 yr old: bout 1 peak, 38.8 ± 0.7°C; bout 2, 38.7 ± 0.6°C), physiological strain index (12–13 yr old: bout 1 peak, 7.9 ± 0.9; bout 2, 7.5 ± 0.7; 16–17 yr old: bout 1 peak, 8.1 ± 1.5; bout 2, 7.9 ± 1.4), or thermal sensation for any age/sex subgroup or for all subjects combined. However, rating of perceived exertion AUC and peak were higher (P = 0.0090 and 0.0004, respectively) during bout 2 in the older age group. Notably, four subjects experienced consistently higher responses throughout bout 2. With these healthy, fit, young athletes, 1 h of complete rest, cool down, and rehydration following 80 min of strenuous exercise in the heat was generally effective in eliminating any apparent carryover effects that would have resulted in greater thermal and cardiovascular strain during a subsequent identical exercise bout.

A short recovery period between same-day rounds of tournament competition is common practice in organized youth sports. With the additional effects imposed by a hot environment on cardiovascular and thermal strain, performance, and exertional heat injury risk (1, 2, 4, 8, 9, 14, 21, 22, 24, 25, 45, 47, 48), the ability to perform safely and effectively through multiple strenuous same-day competition bouts in the heat can be challenging for young athletes (8, 16). The apparent cumulative demands can often result in poor performance or complete withdrawal from play. Wallace et al. (58) found that exertional heat illness risk was more strongly associated with the combined effects of previous-day wet bulb globe temperature (WBT) and current-day heat exposure than with either measure alone, suggesting a cumulative effect on thermal strain during exercise in the field. With same-day exercise, Ronsen et al. (46) found that a longer recovery period between bouts (6 vs. 3 h) attenuated the degree of increased metabolic stress and cardiovascular and thermal strain in the second exercise bout for elite endurance athletes, demonstrating how the extent of residual or carryover effects from a previous exercise session can be modulated by increasing the rest and recovery time between bouts. Several other investigations (12, 28, 52, 61) on adults have also highlighted how recent prior strenuous exercise can prompt greater thermal and cardiovascular strain and perceived effort during a subsequent same-day exercise session, although notably, in these latter studies, the subjects were either not well-hydrated during the test sessions and/or core body temperature was still elevated above baseline before the next exercise bout was begun. Rivera-Brown et al. (44) and Wilk et al. (60) have examined intermittent exercise in the heat with boys and girls; however, the exercise protocols in these studies and other similar investigations must be considered as single exercise sessions, since the data points for each of the repeated exercise and rest periods were analyzed across time collectively, and between-bout pairwise comparisons were not assessed. To date, only one study has examined the relationship of cumulative heat stress exposure on subsequent same-day athletic performance in youths. By examining data over a 7-yr period from a national boys’ tennis championship event, Coyle (16) found that the winner of an afternoon singles match was predictable based on same-day degree minutes acquired during each player’s respective morning matches. These studies strongly support the potential for physiological carryover effects from previous same-day competition-related physical activity having a measurable negative impact on subsequent physiological strain and clinical risk during tournament play, especially in a hot environment, in organized youth sports; however, the influence of such residual factors on cardiovascular, thermoregulatory, and perceptual responses during repeated-bout exercise in the heat under controlled conditions has not been specifically examined in young athletes.

To test the hypothesis that young, fit athletes will experience an increase in physiological strain and perceptual discomfort during a second identical exercise bout in the heat, with 1 h of rest and recovery between bouts and ample hydration, we measured and compared core body temperature (Tc), heart rate (HR), and selected perceptual measures in response to two successive exercise bouts in the heat on the same day. These novel findings extend the literature on repeated-bout exercise.
to children and adolescents and help to establish the necessary evidence-based foundation for determining minimal safe and effective rest periods between same-day contests during tournament play in the heat for a number of outdoor organized youth sports.

**METHODS**

**Subjects.** Twenty-four young, healthy, fit male and female athletes (12–13 yr olds: 6 boys, 6 girls; 16–17 yr olds: 6 boys, 6 girls) participated in this study. All of the subjects regularly participated (at least 2 times per week) in competitive organized soccer, except two (12–13 yr: 1 girl; 16–17 yr: 1 boy) who were similarly involved in other organized competitive youth sports (i.e., volleyball, basketball, and cross-country). All subjects were established residents of the greater Augusta, GA, area and thus had been training and competing regularly for several years or more in a region of the country where the climate is consistently warm to hot for ~9 mo of the year. However, the subjects were tested at different times throughout the school year; consequently, acclimatization to the heat was likely normally distributed. The study was reviewed and approved by the Human Assurance Committee of the Medical College of Georgia, and all subjects (and parents) gave their voluntary, written informed consent to participate in this investigation.

**Aerobic power testing.** Each subject performed a maximal treadmill test (at test temperature) for determining peak aerobic power (V\(_{O_2peak}\)) on a day before his/her repeated-bout test session in the heat. Just before the start of the aerobic power test, each subject performed a progressive 3-min warm-up on the treadmill (Trackmaster TMX22; Full Vision, Newton, KS) to become familiar with the procedures and to determine a comfortable running speed. After the warm-up, each subject briefly stretched and was then fitted with the mouthpiece, nose clip, and measurement apparatus. A modified Balke progressive protocol (59) was used, where each subject ran at a constant speed with an initial grade of 0%. Every 2 min, the grade increased by 2.5% until the subject reached volitional exhaustion or an oxygen uptake plateau was reached. A SensorMedics metabolic system (Vmax Spectra 29c; Yorba Linda, CA) was used for breath-by-breath analysis. HR was monitored continuously using a portable Polar monitor and recorded each minute. Each subject also provided a rating of perceived exertion (RPE) (10) 30 s before the end of each 2-min stage.

**Repeated-bout exercise sessions in the heat.** Each subject completed two identical 80-min exercise bouts in a hot environmental chamber (33°C, 48.9 ± 6.1% relative humidity) separated by 60 min of seated rest in a cool environment (21°C). Upon arrival to the laboratory (0900), each subject emptied his/her bladder and provided a urine sample. The urine samples were used to immediately assess preexercise hydration status, as indicated by urine specific gravity, using a handheld clinical refractometer (Spartan model A 300 CL; Tokyo, Japan). Urine osmolality was determined at a later time, using a freezing-point depression microrefractometer (model 5004; Precision Systems, Natick, MA). Each subject was subsequently weighed (±0.5 g), using a precision scale (model UC-300; A&D Engineering, Milpitas, CA), while wearing a self-selected dry shirt (girls only) and a pair of shorts specifically designated for all body weight measurements (not for exercise). After being weighed, each subject dressed for exercise in a separate outfit (shorts, shirt, underwear, socks, and athletic shoes), and a baseline Tc (see “Core body temperature” was recorded.

After being fitted with a portable HR monitor, each subject entered the environmental chamber and stood for 5 min, while he/she received instructions. The first 80-min intermittent exercise bout consisted of eight 8-min exercise periods, alternating with 8 min on a treadmill followed by 8 min on a bicycle ergometer (Monark Ergomedic 828E; Monark Exercise, Vansbro, Sweden) set at workloads of 60 and 40% of each subject’s V\(_{O_2peak}\) respectively. A 2-min rest period (standing or seated, depending on which exercise modality was next) followed each 8-min exercise period. Tc, HR, and perceived thermal stress, exertion, and gastrointestinal (GI) discomfort were monitored during the entire test session (see Perceptual measures). Preexercise (baseline) measurements for these outcome measures (except perceived exertion) were taken following the 5-min period of standing in the heat. Subsequently, and just before starting exercise, each subject consumed an individualized amount (see Hydration and energy intake standardization) of a commercially available 6% carbohydrate-electrolyte beverage (CHO-E; Gatorade Thirst Quencher: Na\(^+\) concentration, 21.1 mM). Subsequently, each subject drank only CHO-E during the eight 2-min rest periods in equally distributed amounts from the total allotted volume (total volume for each 80-min bout: 13 ml/kg for 12–13-yr olds and 16 ml/kg for 16–17 yr olds). This volume was selected to minimize fluid deficits during exercise while not likely prompting GI discomfort.

Upon completion of the first 80-min exercise bout, each subject exited the environmental chamber and immediately began a 60-min rest and recovery period. Each subject was promptly weighed (after removing the exercise clothing and towel off residual sweat, while wearing the dry clothing designated for all body weight measurements) and then completely emptied his/her bladder into an individual plastic urine collection container so that urine volume could be determined (by weight, ±0.01 g).

Each subject then rested quietly (primarily sitting, although a little walking around and stretching was permitted) for the remainder of the 60-min recovery period. During this time, the subject consumed an individual-specific amount of CHO-E equal to 130% of his/her sweat loss minus the volume consumed during exercise bout1, to ensure complete rehydration (i.e., no remaining exercise-induced fluid deficit from exercise bout 1) before beginning exercise bout 2. The recovery fluid total volume was divided into two equal portions; the first was consumed 15 min into the recovery period, and the second was consumed 15 min before the start of exercise bout 2. During the recovery period, each subject also consumed a small snack (Quaker Chewy Granola Bar: 22 g of carbohydrate, 110 kcal) with the first fluid volume at 15 min into the recovery period. At each of these same two time points, each subject’s Tc, HR, and perception of thermal stress were recorded. In addition, each subject provided a perception of GI discomfort halfway through the recovery period (at 30 min). Just before (~5 min) the start of the second exercise bout, each subject emptied his/her bladder, provided a urine sample (all urine was collected and weighed), and was weighed again. The subject then changed into a second dry set of clothing (similar to that worn in exercise bout 1) for exercise bout 2. The second bout of exercise was conducted in the exact same manner as the first (including having the subject weighed and provide a urine sample following the second exercise bout). Each subject was then monitored during a 15-min postexercise recovery period, to ensure that HR and Tc returned to near baseline values, before being discharged.

**Hydration and energy intake standardization.** For breakfast on the repeated-bout test session day, each subject consumed 385 ml of a commercially available carbohydrate-protein shake (Gatorade Nutrition Shake: 54 g of carbohydrate, 20 g of protein, 370 kcal) at 0700. In addition, each subject consumed a small snack (1 Quaker Chewy Granola Bar: 22 g of carbohydrate, 110 kcal) and 355 ml of CHO-E at 0830 (45 min before the start of exercise). All subjects were encouraged to drink ample water with dinner the day before and some additional water with breakfast on the morning of the day of testing so as to prompt each subject to be well-hydrated before the start of exercise.

**Exercise-induced sweat loss and body mass change.** The amount (ml) of sweat lost during each 80-min exercise bout was estimated from the difference in body mass measurements before and after exercise and the amount of fluid intake during exercise. That is, the amount of sweat lost was estimated to be equal to the combined total of a difference in body mass and fluid consumed (assuming 1 g = 1
ml). A change in body mass (for each 80-min exercise bout) was calculated from the difference between body mass measurements before and after exercise for each subject. Therefore, percent change in body mass was based on initial body mass measured just before each 80-min bout.

**Core body temperature.** An ingestible factory-calibrated temperature sensor telemetry system (CorTemp 2000; HQ, Palmetto, FL) was used to monitor $T_C$, which has been shown and noted to provide a valid and feasible measure of $T_C$ during rest and exercise (13, 39). Each subject ingested (with fluid to assist swallowing) his/her designated sensor in the evening (10–12 h before the beginning of the repeated-bout exercise session) to enhance validity and stability of the $T_C$ measurements and to eliminate potential direct immediate effects of ingested fluid on $T_C$ during the monitoring period. Such a time period should have eliminated the potential temperature fluctuations associated with sensor transit through the stomach and past the liver (39). Moreover, Ducharme et al. (18) reported no effect of sensor associated with sensor transit through the stomach and past the liver period should have eliminated the potential temperature fluctuations (indicated by no transmission signal), the testing was rescheduled for another day. During the monitoring period of each test session, $T_C$ was recorded in each athlete upon arrival at the laboratory, just before the start of each 80-min exercise bout, every 4 min during exercise and at the end of each 2-min rest period, every 15 min during the 1-h recovery period, and 15 min following the end of the second 80-min bout. The sensor was normally excreted (typically within 24 h of ingestion) and did not have to be retrieved. No subject indicated any discomfort or particular difficulties with the use of the temperature sensor.

**Physiological strain index.** During each exercise bout and recovery period, each subject’s $T_C$ and HR were recorded at the same pre-determined time points. As a measure of physiological strain, coincident $T_C$ and HR measures were used to calculate a physiological strain index (PSI) (34).

**Perceptual measures.** Each subject verbally provided a rating of his/her own perception of overall thermal stress (how he/she felt “temperaturewise”) by using a numerical/category scale (1 = intolerably cold, 7 = comfortable, 13 = intolerably hot) that was recorded before exercise, at 4-min intervals during each 80-min exercise bout, and 15 and 45 min into the 60-min recovery period. Each subject also provided a rating of his/her own perception of GI discomfort (how upset his/her stomach felt) by using a numerical/category scale (1 = none, 10 = severe). GI discomfort ratings were provided at the following specific time points: preexercise, at 5-min intervals during each 80-min exercise bout, and 30 min into the 60-min recovery period. In addition, each subject’s own RPE (how hard he/she was working overall) was recorded by using a category ratio scale (7 = very, very light; 19 = very, very hard) (10) at 4-min intervals during each 8-min exercise-period.

**Statistical analysis.** All statistical analyses were performed using SAS 9.1.3, and an alpha level of 0.05 was used to assess statistical significance. The end points of interest in this study were four primary areas under the latency curve (AUC) and respective peak values, as well as differences in urine specific gravity, urine osmolality, sweat loss, and percent change in body mass. The four different AUC and peak values included $T_C$, PSI, rating of thermal stress, and RPE. The predictor variables were sex, age (young vs. older group), and bout. We examined AUC because it more closely reflects the degree and duration of thermal, cardiovascular, and perceptual strain for each bout overall compared with average or peak responses alone. Repeated-measures ANOVA using mixed models was used to examine age group or sex interactions with bout. The three-way interaction with age, sex, and bout was examined for each outcome measure, and none was statistically significant. We reduced the models to two-way interaction models and then to main effects models when appropriate. A Bonferroni adjustment to the overall alpha level was used to examine pairwise post hoc differences. Finally, if age and sex were nonsignificant in the main effects model, a paired t-test was used to examine unadjusted differences between bouts. As an additional analysis of $T_C$, HR, and RPE, differences between bouts within each examination time point of baseline, 40, 50, 60, 70, and 80 min were examined using repeated-measures ANOVA models and a Bonferroni correction to the alpha level ($\alpha = 0.05/6 = 0.0083$), due to the number of time points examined.

### RESULTS

**Sample characteristics.** Twenty-four subjects completed the study. The sample characteristics are presented in Table 1, including the results of the aerobic power testing, which reflected typical levels of aerobic endurance characteristic of such highly skilled and trained young athletes (41, 55, 56).

**Repeated-bout exercise sessions in the heat.** The hydration-related measures and calculated values for both 80-min exercise sessions are shown in Table 2. The data are presented for each age group to particularly highlight the age group differences in exercise-induced sweat loss ($P = 0.0002$) and yet concomitant respective similarities ($P > 0.05$) between age groups in the other outcome measures related to hydration status. Preexercise urine specific gravity (for all subjects combined) was higher in bout 2 compared with bout 1 ($1.025 \pm 0.007$ vs. $1.021 \pm 0.007$, respectively; $P = 0.009$).

### Table 1. Sample characteristics

<table>
<thead>
<tr>
<th>Age, yr</th>
<th>12.6 ± 0.5 (6 Boys, 6 Girls)</th>
<th>16.5 ± 0.5 (6 Boys, 6 Girls)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height, cm</td>
<td>160.1 ± 9.4</td>
<td>166.0 ± 8.0</td>
</tr>
<tr>
<td>Mass, kg</td>
<td>47.7 ± 8.3</td>
<td>61.0 ± 8.6</td>
</tr>
<tr>
<td>BMI</td>
<td>18.1 ± 1.8</td>
<td>21.9 ± 2.0</td>
</tr>
<tr>
<td>$V_{O_2,max}$, ml·kg$^{-1}$·min$^{-1}$</td>
<td>55.5 ± 4.5</td>
<td>55.2 ± 8.3</td>
</tr>
</tbody>
</table>

Values are means ± SD ($n = 24$). BMI, body mass index; $V_{O_2,max}$, peak oxygen uptake.

### Table 2. Hydration-related measures and calculated values for both 80-min exercise sessions in each age group

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Preexercise USG</th>
<th>Preexercise UOsm, mosmol/kgH$_2$O</th>
<th>Sweat loss, ml</th>
<th>$%DBM$</th>
</tr>
</thead>
<tbody>
<tr>
<td>12–13 Yr Olds (6 Boys, 6 Girls)</td>
<td>1.021 ± 0.006</td>
<td>768.1 ± 221.5</td>
<td>943.6 ± 237.1</td>
<td>−0.9 ± 0.5</td>
</tr>
<tr>
<td>Bout 1</td>
<td>1.024 ± 0.007</td>
<td>731.6 ± 156.1</td>
<td>955.5 ± 250.3</td>
<td>−1.0 ± 0.5</td>
</tr>
<tr>
<td></td>
<td>Bout 2</td>
<td>1.021 ± 0.009</td>
<td>588.1 ± 291.5</td>
<td>1382.2 ± 480.7</td>
</tr>
<tr>
<td>16–17 Yr Olds (6 Boys, 6 Girls)</td>
<td>1.025 ± 0.007</td>
<td>664.1 ± 255.3</td>
<td>1373.1 ± 472.2</td>
<td>−0.8 ± 0.5</td>
</tr>
</tbody>
</table>

Values are means ± SD. USG, urine specific gravity; UOsm, urine osmolality; $\%DBM$, percent change in body mass.
The TC (Fig. 1), HR (Fig. 2), PSI (Fig. 3), rating of thermal stress (Fig. 4), and RPE responses (Fig. 5) during the two exercise bouts are shown for each age and sex subgroup. One AUC outcome and one peak outcome showed a statistically significant interaction with age group (Table 3), indicating that the effect of bout on the outcome is different in the two age groups. Specifically, the effect of bout on the AUC RPE and peak RPE was different in the two age groups. In the younger age group, the AUC RPE had a slight, nonsignificant change between bouts 1 and 2 ($P = 0.8738$), whereas in the older age group, the AUC RPE increased significantly between bouts 1 and 2 ($P = 0.0090$). For peak RPE, the younger age group had a nonsignificant decrease between bouts 1 and 2 ($P = 0.9229$), whereas the older age group had a significant increase in peak RPE between bouts 1 and 2 ($P = 0.0004$). There were no statistically significant interactions between sex and bout for any outcome (Table 4).

Examining the paired t-tests (Table 5) indicated statistically significant differences between bouts 1 and 2 for peak TC, peak

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**Fig. 1.** Core body temperature responses during the 2 exercise bouts in the heat for each age (young, 12–13 yr old; older, 16–17 yr old) and sex subgroup. Pre, preexercise; Post15, 15 min after exercise completion. Values are means ± SE.

**Fig. 2.** Heart rate (bpm, beats/min) responses during the 2 exercise bouts in the heat for each age and sex subgroup. Values are means ± SE.
HR, AUC PSI, and peak PSI. In each instance, values in bout 2 were significantly lower than in bout 1.

Examining TC, HR, and RPE within each selected time point (baseline and over the latter half of each exercise bout; Table 6) indicated a statistically significant difference between bouts for only one outcome at one time point. HR was significantly higher during bout 2 than during bout 1 at baseline. There were no statistically significant differences in any other of these time points between bouts for TC, HR, or RPE.

Four young athletes individually experienced consistently greater physiological and perceptual strain throughout the second exercise bout (Fig. 6). These were the only subjects whose TC and HR responses were consistently higher in bout 2 (compared with their own individual responses in bout 1);
however, there were no other distinguishing or remarkable characteristics (e.g., urine specific gravity, sweat loss, or other measure).

**DISCUSSION**

In contrast to our hypothesis, there were no between-bout statistical differences in our measures of thermal and cardiovascular strain for any age/sex subgroup or all subjects combined. However, the greater RPE with the older subjects in exercise bout 2 suggests incomplete recovery and fatigue-related residual or carryover effects from the previous exercise session for this group. Accordingly, these findings and the notable other responses of some subjects indicate that previous strenuous exercise and heat exposure can have a measurable negative impact on subsequent similar exercise in the heat in young, fit athletes, even when ample hydration is provided.

**Cardiovascular and thermal strain.** In contrast to previous studies on repeated-bout same-day exercise in adults (12, 28, 46, 52, 61), our subjects (as a group) did not experience greater cardiovascular or thermal strain during the second bout of exercise (except at baseline for HR only), as evidenced by no statistical differences in AUC or peak values for TC, HR, PSI, or thermal sensation between exercise bouts. Although these other studies were able to show measurable increases in TC and HR during subsequent bouts of exercise with and without external heat stress and utilizing a wide range of strenuous exercise durations and recovery period lengths, it should be noted that rehydration was insufficient and/or thermoregulatory

### Table 3. Age group × bout differences in outcomes from repeated-measures ANOVA mixed model containing the age group × bout interaction and the sex × bout interaction

<table>
<thead>
<tr>
<th></th>
<th>12-13 Yr Olds</th>
<th>16-17 Yr Olds</th>
<th>Age Group × Bout, F Value (P Value)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bout 1</td>
<td>Bout 2</td>
<td>Bout 1</td>
</tr>
<tr>
<td>AUC T&lt;sub&gt;c&lt;/sub&gt;, °C</td>
<td>3,582.17 ± 30.34</td>
<td>3,612.94 ± 7.23</td>
<td>F = 0.43 (P = 0.5194)</td>
</tr>
<tr>
<td>Peak HR, beats/min</td>
<td>182.37 ± 2.44</td>
<td>179.42 ± 2.52</td>
<td>F = 0.16 (P = 0.6930)</td>
</tr>
<tr>
<td>AUC PSI</td>
<td>998.51 ± 32.34</td>
<td>992.71 ± 46.22</td>
<td>F = 0.43 (P = 0.0038)</td>
</tr>
<tr>
<td>Peak PSI</td>
<td>16.09 ± 0.51</td>
<td>16.05 ± 0.58</td>
<td>F = 9.40 (P = 0.0055)</td>
</tr>
<tr>
<td>AUC thermal stress</td>
<td>916.46 ± 31.33</td>
<td>979.88 ± 39.55</td>
<td>F = 0.68 (P = 0.4170)</td>
</tr>
<tr>
<td>AUC PSI</td>
<td>540.18 ± 25.73</td>
<td>474.46 ± 27.70</td>
<td>F = 3.33 (P = 0.0811)</td>
</tr>
<tr>
<td>Peak PSI</td>
<td>7.98 ± 0.30</td>
<td>7.32 ± 0.26</td>
<td>F = 3.27 (P = 0.0838)</td>
</tr>
<tr>
<td>AUC GI</td>
<td>145.86 ± 21.92</td>
<td>125.54 ± 19.31</td>
<td>F = 0.34 (P = 0.5656)</td>
</tr>
<tr>
<td>Peak GI</td>
<td>2.71 ± 0.46</td>
<td>2.62 ± 0.49</td>
<td>F = 0.20 (P = 1.0000)</td>
</tr>
</tbody>
</table>

Values are adjusted least-square means ± SE. F statistics and P values come from repeated-measures ANOVA models containing age group × bout and sex × bout interactions. AUC, area under the curve; T<sub>c</sub>, core body temperature; HR, heart rate; RPE, rating of perceived exertion; PSI, physiological strain index; GI, perceived gastrointestinal discomfort.
recovery was not achieved between bouts, which likely contributed to the augmented physiological strain observed in these investigations. This is a primary difference in our study. We provided ample hydration during each exercise bout, and our subjects consumed enough fluid during the recovery period to offset any remaining exercise-induced fluid deficit. Moreover, Inbar et al. (26) reported that children have more efficient sweating and more effective thermoregulation compared with adults, which can offset age-related differences in relative metabolic heat production, sweating, and environmental heat gain. This may have played a contributing role in our study as well.

Although the preexercise urine specific gravity measures (Table 2) might suggest otherwise (higher at the start of bout 2), our subjects could have been better hydrated at the beginning of exercise bout 2 (compared with bout 1, given the between-bouts complete rehydration protocol described in METHODS), which has been shown to reduce physiological strain and enhance heat tolerance in children and adolescents (6, 8, 17, 19, 45, 47). Urine specific gravity generally provides a valid indication of hydration status (5), although urine osmolality is also used and sometimes preferred, especially when plasma osmolality is not available (53, 62). However, recent fluid (volume and type) and food intake, exercise, and heat exposure can alter renal hemodynamics and thus the accuracy in interpreting these measures to reflect acute total body water gains or losses due to associated changes in plasma osmolality, body water distribution, and volume fluctuations in fluid compartments (3, 20, 29–31, 35, 36, 40, 50, 51, 57). Moreover, variations in urine specific gravity and osmolality lag behind rapid changes in sweat losses or fluid intake (42). Besides having a potential influence on urine hydration status measures, CHO-E also may have enhanced (compared with water) total body hydration by ensuring greater fluid retention and may be less pronounced with adolescents (23). Without the expected difference in physiological strain during bout 2 in our study, it is apparent that other contributing carryover effects from the first strenuous exercise session may have altered

Table 5. Paired t-test results for differences between bouts

<table>
<thead>
<tr>
<th></th>
<th>Bout 1</th>
<th>Bout 2</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUC $T_C$</td>
<td>3.604.11 ± 114.91</td>
<td>3.619.17 ± 26.96</td>
<td>0.5046</td>
</tr>
<tr>
<td>Peak $T_C$, °C</td>
<td>38.69 ± 0.51</td>
<td>38.52 ± 0.41</td>
<td>0.0078</td>
</tr>
<tr>
<td>AUC HR</td>
<td>14.430.23 ± 821.14</td>
<td>13.942.65 ± 173.76</td>
<td>0.1636</td>
</tr>
<tr>
<td>Peak HR, beats/min</td>
<td>181.69 ± 8.99</td>
<td>179.18 ± 9.41</td>
<td>0.0020</td>
</tr>
<tr>
<td>AUC thermal stress</td>
<td>926.77 ± 112.40</td>
<td>908.75 ± 145.26</td>
<td>0.4727</td>
</tr>
<tr>
<td>Peak thermal stress</td>
<td>10.96 ± 1.18</td>
<td>10.92 ± 1.35</td>
<td>0.8019</td>
</tr>
<tr>
<td>AUC PSI</td>
<td>540.35 ± 99.45</td>
<td>520.08 ± 105.14</td>
<td>0.0390</td>
</tr>
<tr>
<td>Peak PSI</td>
<td>8.08 ± 1.18</td>
<td>7.64 ± 1.07</td>
<td>0.0038</td>
</tr>
<tr>
<td>AUC GI</td>
<td>138.46 ± 78.68</td>
<td>125.96 ± 68.97</td>
<td>0.3746</td>
</tr>
<tr>
<td>Peak GI</td>
<td>2.65 ± 1.65</td>
<td>2.58 ± 1.75</td>
<td>0.7986</td>
</tr>
</tbody>
</table>

Values are means ± SD.

Table 6. Repeated-measures ANOVA results for differences between bouts within time points

<table>
<thead>
<tr>
<th></th>
<th>Bout 1</th>
<th>Bout 2</th>
<th>F Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_C$, °C</td>
<td>37.27 ± 0.04</td>
<td>37.22 ± 0.04</td>
<td>0.60</td>
</tr>
<tr>
<td>40 min</td>
<td>38.30 ± 0.07</td>
<td>38.23 ± 0.07</td>
<td>0.48</td>
</tr>
<tr>
<td>50 min</td>
<td>38.45 ± 0.07</td>
<td>38.35 ± 0.07</td>
<td>0.91</td>
</tr>
<tr>
<td>60 min</td>
<td>38.50 ± 0.08</td>
<td>38.38 ± 0.08</td>
<td>1.16</td>
</tr>
<tr>
<td>70 min</td>
<td>38.60 ± 0.08</td>
<td>38.49 ± 0.09</td>
<td>0.89</td>
</tr>
<tr>
<td>80 min</td>
<td>38.54 ± 0.09</td>
<td>38.49 ± 0.10</td>
<td>0.12</td>
</tr>
<tr>
<td>HR, beats/min</td>
<td>93.96 ± 2.54</td>
<td>105.00 ± 2.54</td>
<td>9.45</td>
</tr>
<tr>
<td>40 min</td>
<td>142.88 ± 2.35</td>
<td>139.60 ± 2.40</td>
<td>0.96</td>
</tr>
<tr>
<td>50 min</td>
<td>143.50 ± 2.39</td>
<td>137.56 ± 2.44</td>
<td>3.02</td>
</tr>
<tr>
<td>60 min</td>
<td>143.69 ± 2.90</td>
<td>142.24 ± 2.96</td>
<td>0.35</td>
</tr>
<tr>
<td>70 min</td>
<td>141.85 ± 2.68</td>
<td>141.96 ± 2.79</td>
<td>0.00</td>
</tr>
<tr>
<td>80 min</td>
<td>143.69 ± 2.50</td>
<td>142.63 ± 2.60</td>
<td>0.09</td>
</tr>
</tbody>
</table>

Values are adjusted least-square means ± SE. *Statistically significant at the Bonferroni adjusted alpha level of 0.05/6 = 0.0083 for each outcome.
cerebral metabolism and elevated central hyperthermic fatigue and thus prompted a change in neuromuscular efficiency and kinematics and increased perceived exertion for the older group (15, 23, 43, 49).

**Bout 2 responders.** Notably, four young athletes individually had consistently higher $T_c$, HR (and PSI), and RPE responses in bout 2 compared with their first exercise session, which might indicate a lower tolerance (33) to repeated strenuous exercise in the heat and a potential greater clinical risk for these particular boys and girls during outdoor multiple-bout competition scenarios in hot weather. Although we did not evaluate any humoral measures to support the argument, we suspect that the greater degree of physiological strain observed in bout 2 was more likely related to a greater (albeit subclinical) pyrogenic response to the first period of exercise, thus contributing to the higher $T_c$ and cardiac frequency (11), as opposed to an acute exercise-induced inflammatory reaction to any potential muscle damage incurred (32) during bout 1. The responses of these individuals also underscore the fact that ample hydration does not guarantee minimal thermal and cardiovascular strain.

**Relevance to youth sports.** This is the first examination of repeated-bout strenuous exercise in the heat, separated by a period of rest, rehydration, and thermoregulatory recovery, with youth. We chose a 1-h between-bout recovery period to address a typical youth sports tournament format where often only a short rest period is provided between multiple same-day contests (7, 54). The additional effects imposed by the heat on cardiovascular and thermal strain helped to replicate the more challenging environmental conditions that numerous young athletes often face while participating in outdoor venues. Moreover, our chosen intermittent protocol (compared with continuous exercise) was selected to more closely mimic the activity patterns of certain outdoor youth sports (e.g., tennis and soccer) and the greater physiological strain characteristic of such intermittent work (27). We also tried to further simulate youth tournament behavior by having the subjects consume a small standardized breakfast and snack before coming to the test session and nutritionally recover from the first bout with only CHO-E and the same small snack. However, it is important to note that the boys and girls were immediately removed from the heat after the first exercise session and that they rested for the entire recovery period. They also consumed enough fluid (CHO-E) to offset any remaining postexercise fluid deficit, and their $T_c$ returned to baseline (same as before bout 1) before the second exercise bout began. These “ideal” conditions are in stark contrast to more typical youth sports tournament scenarios, where complete thermoregulatory recovery and rehydration are less likely to occur, because the athletes do not totally rest and rehydrate and remain in a cool environment between contests (8). Moreover, the next round of competition is often contested later in the day when it is hotter (8). Thus, without the same physiological advantages provided by our laboratory protocol, it is reasonable to expect a greater impact (than we observed) of previous strenuous physical activity and heat exposure on subsequent same-day exercise-related physiological and perceptual strain in the field with a concomitant negative effect on performance (16).

**Study limitations and future research.** The protocol utilized in this study provided the opportunity to examine the effects of a previous exercise bout on subsequent physiological and perceptual strain without potential confounders (that are typically present in youth sports scenarios) such as incomplete rehydration or only partial thermoregulatory recovery when starting the second session. However, without knowing the precise hydration status of the subjects just before the start of the first exercise bout, we cannot rule out the possibility that the physiological and perceptual outcome measures in bout 2 were measurably influenced by improved hydration status. Moreover, other aspects of nutritional status (e.g., recent prior intake of carbohydrate and protein) were somewhat different for each bout of exercise and might have affected the subjects’ responses during exercise. However, these dietary behaviors
are typical of young athletes participating in same-day multiple-bout competitions, and we were attempting to reflect this in the protocol.

This study is a first step in examining repeated-bout strenuous exercise in youth. However, because of the physiological advantages provided by our protocol (i.e., complete rest, full rehydration, and $T_C$ returning to baseline between bouts), the relatively high fitness level of the subjects, and only moderate heat stress, it would be invalid to extend these findings to what would be expected in the field with all children and adolescents competing in various youth sports events across a wide range of environmental conditions. Moreover, additional dependent variables, such as circulating metabolic or hormonal responses or muscle function and performance tests, could have provided further insight to measurable carryover effects in our protocol.

Much more research is warranted to appreciate the impact of previous same-day exercise and competition-related physical activity in various environmental conditions and with workloads, fatigue, recovery periods, hydration status, and maturation levels reflecting a broader scope of youth sports scenarios so that the most appropriate evidence-based guidelines for safely and effectively scheduling and managing multiple competition bouts in the heat can be provided to optimize performance and reduce the risk of exertional heat injury in organized youth sports.

Summary and conclusions. In summary, with these healthy, fit, young athletes, 1 h of complete rest, cool down, and rehydration following 80 min of strenuous exercise in the heat was generally effective in eliminating any apparent residual or carryover effects that would have resulted in greater thermal and cardiovascular strain during a subsequent identical exercise bout. However, for some, this recovery period and protocol were insufficient to avert greater perception of effort and physiological strain during the second bout. Moreover, during outdoor youth sports tournaments in the heat, young athletes typically do not have the opportunity to promptly get out of the heat and completely rehydrate and cool down between games or matches. Accordingly, our findings support previous laboratory and field studies on adults to the extent that there is a potential for the residual or carryover effects from a recent prior bout of strenuous exercise and heat exposure to decrease performance and increase clinical risk during a subsequent same-day exercise bout in the heat, even when hydration is maintained and $T_C$ returns to baseline between bouts. Therefore, on the basis of our findings and those from other related studies cited in this report, youth sports governing bodies, tournament directors, and other event administrators should recognize and appreciate that providing longer rest and recovery periods between contests during hot weather events may improve athlete performance and safety. Moreover, organizers of tournaments and multiple same-day practice sessions for youth in the heat also should consider the potential effects of exercise and heat exposure from the previous day, even if the current day appears “safe,” to minimize exertional heat injury risk.

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REFERENCES


