Exercise-rest cycles do not alter local and whole body heat loss responses

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Gagnon D, Kenny GP. Exercise-rest cycles do not alter local and whole body heat loss responses. Am J Physiol Regul Integr Comp Physiol 300: R958–R968, 2011. First published January 26, 2011; doi:10.1152/ajpregu.00642.2010.—Previous studies have suggested that greater core temperatures during intermittent exercise (Ex) are due to attenuated sweating [upper back sweat rate (SR)] and skin blood flow (SkBF) responses. We evaluated the hypothesis that heat loss is not altered during exercise-rest cycles (ER). Ten male participants randomly performed four 120-min trials: 1) 60-min Ex and 60-min recovery (60ER); 2) 3 × 20-min Ex separated by 20-min recoveries (20ER); 3) 6 × 10-min Ex separated by 10-min recoveries (10ER), or 4) 12 × 5-min Ex separated by 5-min recoveries (5ER). Exercise was performed at a workload of 130 W at 35°C. Whole body heat exchange was determined by direct calorimetry. Core temperature, SR (by ventilated capsule), and SkBF (by laser-doppler) were measured continuously. Evaporative heat loss (EHL) progressively increased with each ER, such that it was significantly greater (P < 0.05) at the end of the last compared with the first Ex for 5ER (299 ± 39 vs. 440 ± 41 W), 10ER (425 ± 51 vs. 519 ± 45 W), and 20ER (515 ± 63 vs. 575 ± 74 W). The slope of the EHL response against esophageal temperature significantly increased from the first to the last Ex within the 10ER (376 ± 56 vs. 445 ± 89 W/°C, P < 0.05) and 20ER (535 ± 85 vs. 588 ± 28 W/°C, P < 0.05) conditions, but not during 5ER (296 ± 96 W/°C vs. 278 ± 95 W/°C, P = 0.237). In contrast, the slope of the SkBF response against esophageal temperature did not significantly change from the first to the last Ex (5ER: 51 ± 23 vs. 54 ± 19%/°C, P = 0.848; 10ER: 53 ± 8 vs. 56 ± 21%/°C, P = 0.786; 20ER: 44 ± 20 vs. 50 ± 27%/°C, P = 0.432). Overall, no differences in body heat content and core temperature were observed. These results suggest that altered local and whole body heat loss responses do not explain the previously observed greater core temperatures during intermittent exercise.

INTERMITTENT EXERCISE IS TYPICAL OF many occupational and military activities. In most cases, the intermittent aspect of these activities is inherent to the task(s) being performed. However, intermittent exercise is also used by many health and safety industries (1, 18), as well as the US military (24), as a strategy to minimize the risk of exertional heat strain when these activities are performed in hot and/or humid environments.

The benefit of exercise-rest cycles is to decrease the time-weighted average rate of metabolic heat production for a given task, which, when combined with sufficient recovery periods, should maintain core temperature below 38°C (1, 18). However, studies examining differences in core temperature between continuous and intermittent exercise have yielded conflicting results. In general, when the exercise periods are of long duration and/or performed under compensable conditions, continuous and intermittent exercise result in similar increases in core temperature (2, 3, 5, 13–15, 22). In contrast, greater increases in core temperature have been reported during intermittent exercise consisting of short exercise-rest cycles performed under both compensable (4, 17) and uncompensable (13) conditions. Although the specific reason(s) for these discrepancies is unclear, studies that report greater core temperatures during intermittent exercise have consistently attributed this response to altered heat loss responses (4, 13, 17).

It is surprising to note, however, that there exists relatively limited research that directly compares the control of heat loss responses between intermittent and continuous exercise, as most studies only examine core temperature responses. Ekblom et al. (4) attributed a greater increase in core temperature during intermittent exercise to a lower overall loss of body weight (i.e., evaporative heat loss), while Kraning and González (13) implied reduced skin blood flow (SkBF) through core to skin temperature gradients. To our knowledge, only More-Rodriguez et al. (17) have reported continuous measurements of heat loss responses during both continuous and intermittent exercise, observing lower SkBF values during the intermittent condition. However, their observations were limited to one intermittent protocol and did not include analyses of thermal sensitivities. Therefore, it remains to be determined whether heat loss responses are altered during different exercise-rest cycles ranging from short-to-moderate duration and whether intermittent exercise alters the control (as determined by the thermal sensitivity) of heat loss responses.

To this effect, the purpose of this study was to examine differences in local SkBF and sweat rate (SR) and whole body (evaporative and dry) heat loss responses between continuous and different exercise-rest cycles ranging from short (i.e., 12 exercise-rest cycles of 5-min each) to moderate (i.e., 3 exercise-rest cycles of 20-min each) duration performed at a fixed rate of metabolic heat production. We chose a fixed exercise intensity to eliminate any possible confounding influences of varying rate of metabolic heat production. We chose a fixed exercise intensity to eliminate any possible confounding influences of varying rate of metabolic heat production. We chose a fixed exercise intensity to eliminate any possible confounding influences of varying rate of metabolic heat production. We chose a fixed exercise intensity to eliminate any possible confounding influences of varying rate of metabolic heat production.

MATERIALS AND METHODS

Participants

Following approval of the experimental protocol from the University of Ottawa Research Ethics Committee and obtaining written informed consent, 10 healthy, nonsmoking, normotensive male par-
Participants volunteered for the study. Mean ± SD physical characteristics of the participants were: age, 23 ± 4 yr; height, 177 ± 7 cm; weight, 75.4 ± 6.5 kg; maximum oxygen uptake, 57.9 ± 7.0 ml O₂·kg⁻¹·min⁻¹; and body fat percent, 12.5 ± 4.7%.

Experimental Design

All participants undertook one screening visit and four experimental sessions. During the screening visit, body density and maximum oxygen uptake were measured. Body density was measured using the hydrostatic weighing technique, and body fat percentage was then calculated using the Siri equation (23). Maximum oxygen uptake was determined by measuring expired oxygen (O₂) and carbon dioxide (CO₂) concentrations (AMETEK models S-3A/1 and CD 3A; Applied Electrochemistry, Pittsburgh, PA) during a progressive incremental cycling protocol performed on an upright seated ergometer bicycle. Subjects were asked to cycle continuously at 80 rpm, at a starting work rate of 40 W for 2 min. The work rate was then increased by 40-W increments every 2 min thereafter, until the subject could not maintain a pedaling cadence of at least 60 rpm.

During the four experimental sessions, the calorimetry exercise protocol was performed. To control for seasonal acclimatization, all experimental trials were performed during the months of October and April. Testing days were separated by a minimum of 72 h. All calorimeter trials were performed at the same time of day. Participants were asked to arrive at the laboratory after eating a small breakfast (i.e., dry toast and juice), but consuming no tea or coffee that morning, and also avoiding any major thermal stimuli on their way to the laboratory. Participants were also asked to not drink alcohol or exercise for 24 h prior to experimentation. For all experimentation, clothing insulation was standardized at 0.2 to 0.3 clo (i.e., cotton underwear, running shorts, and sandals).

Following instrumentation, the participant entered the calorimeter regulated to an ambient air temperature of 35°C and a relative humidity of 20%. The participant, seated in the upright position, rested for a 60-min habituation period, while a steady-state baseline condition was achieved. Subsequently, the participant performed a total of 60 min of exercise and 60 min of recovery divided into one of the following exercise-rest (ER) cycles: 1) one bout of 60-min exercise followed by one 60-min recovery period (60ER); 2) three bouts of 20-min exercise each separated by 20-min recovery periods (20ER); 3) six bouts of 10-min exercise each separated by 10-min recovery periods (10ER), or 4) 12 bouts of 5-min exercise each separated by 5-min recovery periods (5ER). The exercise periods consisted of upright seated cycling at a fixed external workload of 130 W. During the recovery periods, the participants remained seated on the cycle ergometer in the upright position. Each participant performed, in a random order, all four experimental sessions.

Measurements

The individual components of the heat balance equation were measured by combined direct and indirect calorimetry (6). The modified Snellen air dry calorimeter was employed for the purpose of measuring whole body heat exchange as described in detail previously (7, 11). A full peer-reviewed technical description of the performance and calibration characteristics of the Snellen whole body calorimeter is available (21). Data from the direct calorimeter were collected continuously at 8-s intervals throughout the trials. The real-time data were displayed and recorded on a personal computer with LabVIEW software (version 7.0; National Instruments, Austin, TX).

Indirect calorimetry was used for the concurrent measurement of metabolic energy expenditure (19). Expired gas was analyzed for O₂ (error of ±0.01%) and CO₂ (error of ±0.02%) concentrations using electrochemical gas analyzers located outside of the calorimeter chamber (AMETEK models S-3A/1 and CD 3A; Applied Electrochemistry). Expired air was recycled back into the calorimeter chamber to account for respiratory dry and evaporative heat loss. Prior to each session, gas mixtures of 4% CO₂-17% O₂ and balance nitrogen were used to calibrate the gas analyzers and a 3-liter syringe was used to calibrate the turbine ventilometer (error of ±3%, typically <1%).

The direct and indirect calorimetry data were subsequently used to calculate change in body heat content (7, 11).

Forearm SkBF was estimated using laser-Doppler velocimetry (Periflux System 5000; Perimed, Stockholm, Sweden) at the right mid-forearm anterior. Prior to the start of the experimental trial, the laser-Doppler flow probe (model PR 401 Angled Probe; Perimed) was affixed with adhesive rings to the ventral forearm in a site without superficial veins that demonstrated high flux values and pulsatile activity. To account for the fact that the location of the laser-Doppler flow probe was not marked between trials for a given subject, local skin temperature at the skin site was raised to 44°C (rate of ~1.5°C/min at the end of each experimental trial by using a heating element (model PF 5020 Temperature Unit; Perimed) housing the laser-Doppler flow probe. The element was activated until a plateau in SkBF was attained (~30 to 45 min). Since absolute perfusion units arguably represent a better indication of local heat dissipation, SkBF data are represented as a percentage of maximum flux values. Upper arm blood flow rate (SR) was estimated from a 5.0-cm² ventilated capsule. Anhydrous compressed air was passed through the capsule over the skin surface at a rate of 1 l/min. Water content of the effluent air was measured at known barometric pressure using the readings from an HX93 humidity and temperature sensor (Omega Engineering, Stamford, CT). SR was calculated using the difference in water content between effluent and influent air, and the flow rate. This value was normalized for the skin surface area under the capsule and expressed in milligrams per minute per centimeter squared.

Esophageal temperature was measured by placing a pediatric thermocouple probe of ~2 mm in diameter (Mon-a-therm Nasopharyngeal Temperature Probe; Mallinckrodt Medical, St. Louis, MO) through the participant’s nostril while they were asked to sip water (maximum of 250–500 ml) through a straw. Following the insertion of the esophageal probe, the participants did not consume any fluids until the end of the experimental trial. The esophageal probe was inserted to a length based on the participant’s standing height (16).

Rectal temperature was measured using a pediatric thermocouple probe (Mon-a-therm General Purpose Temperature Probe) inserted to a maximum of 12 cm past the sphincter. Skin temperature was measured using 0.3-mm diameter T-type (copper/constantan) thermocouples (Concept Engineering, Old Saybrook, CT) that were attached to the skin using surgical tape. Mean skin temperature was calculated using four skin temperatures weighted to the following regional proportions: upper arm: 30%; chest: 30%; quadriceps: 20%; and back calf: 20% (20). Temperature data were collected using an HP Agilent data acquisition module (model 3497A) at a sampling rate of 15 s and simultaneously displayed and recorded in spreadsheet format on a personal computer with LabVIEW software (version 7.0, National Instruments).

Heart rate was monitored using a Polar coded transmitter, recorded continuously, and stored with a Polar Advantage interface and Polar Precision Performance software (Polar Electro Oy, Kempele, Finland).

Thermal sensation was recorded throughout each condition using an ASHRAE 7-point scale ranging from neutral (0) to extremely hot (7). Ratings of perceived exertion were also noted during the exercise periods using the Borg scale, ranging from 6 (no exertion at all) to 20 (maximal exertion). Each scale was affixed inside the calorimeter, and during the last minute of each exercise/recovery period, the participants were asked to verbally provide their ratings of thermal sensation and perceived exertion.

Statistical Analysis

For all variables, minute averages were performed following data collection to carry out the statistical analyses. To determine the
thermal sensitivity of the evaporative heat loss and forearm SkBF responses, the slope of each response against esophageal temperature was analyzed using a simple linear regression, with the slope of the relationship taken as the thermal sensitivity.

To better illustrate the statistical analyses performed, the comparisons made can be grouped into two statistical analyses: (1) comparisons made between the intermittent (i.e., 5ER, 10ER, 20ER) and continuous (i.e., 60ER) conditions, and (2) comparisons made within a given intermittent condition.

Analysis 1. The purpose of the first analysis was to compare the measured variables between a given intermittent condition (i.e., 5ER, 10ER, and 20ER) and the 60ER condition. Since the intermittent conditions contained periods of rest between the exercise bouts, which occurred at different intervals, analyzing the variables across time would not provide fair comparisons between conditions as values during the recovery period of one condition (e.g., 5ER) might be compared with those measured during the exercise period of another condition (e.g., 20ER). Consequently, we opted to carry out the statistical analyses at common time points for all experimental conditions: (a) baseline, (b) end of the first exercise bout, (c) end of the last exercise bout, and (d) end of the experimental protocol. It is important to note that we were only interested in examining whether the measured variables differed between conditions at either one of these given time points. We were not interested in determining whether the measured variables changed differently over these time points between experimental conditions. As such, each time point was treated as a separate analysis.

The end of the first exercise bout, comparison (i.e., b) was performed to determine whether the initial response to exercise was similar between a given intermittent condition and the 60ER condition. To do so, we compared values at the end of the first exercise bout during the intermittent conditions to the corresponding time point during 60ER. Therefore, values at the 5-, 10-, and 20-min time points of exercise during 60ER were used for the 5ER-60ER, 10ER-60ER, and 20ER-60ER comparison, respectively. Since we were only interested in comparing a specific intermittent condition to the 60ER condition, rather than comparing all conditions between each other, this analysis was carried out using three separate paired samples t-tests.

The end of the last exercise bout comparison (i.e., c) was used to examine differences in peak values attained during each experimental protocol. This was done by comparing values from the last minute of exercise during 60ER to the last minute of the 12th, 6th, and 3rd exercise bout of the 5ER, 10ER, and 20ER conditions, respectively.

To compare the overall change in the measured variables between the intermittent and continuous conditions (i.e., d), we compared values at the end of the experimental protocol (after 60 min of exercise and 60 min of recovery were completed). Since each time point (i.e., a, c, and d) was considered as separate analyses, these comparisons were analyzed using three separate one-way repeated-measures ANOVA with the repeated factor of condition only (i.e., 5ER, 10ER, 20ER, and 60ER).

Analysis 2. The purpose of the second analysis was to analyze the measured variables within a given intermittent condition to determine whether multiple exercise-rest cycles affected any of the measured variables. This was done by comparing values at the end of the last exercise bout to those at the end of the first exercise bout using paired samples t-tests (i.e., 5ER: Ex1 vs. Ex12; 10ER: Ex1 vs. Ex6; 20ER: Ex1 vs. Ex3).

For all analyses, the level of significance was set at an alpha level of 0.05, and adjusted using the Holm-Bonferroni method during multiple comparisons so as to maintain the rate of type I error at 5%. All analyses were performed using commercially available statistical software (SPSS 18.0 for Windows; SPSS, Chicago, IL). All values are reported as means ± SD unless otherwise indicated.

RESULTS

Analysis 1: Comparisons Between the Intermittent and Continuous Conditions

Baseline. There were no significant differences between conditions in baseline rates of metabolic heat production (P = 0.638), total heat loss (P = 0.845), evaporative heat loss (P = 0.817), and dry heat exchange (P = 0.950). Similarly, there were no significant differences in baseline forearm SkBF (P = 0.143) and upper back SR (P = 0.887). Furthermore, there were no significant differences between conditions in baseline esophageal (P = 0.519), rectal (P = 0.354), and mean skin (P = 0.922) temperatures as well as for heart rate (P = 0.419). Baseline thermal sensation averaged 1.6 ± 0.9, 1.7 ± 1.1, 1.2 ± 0.8, and 1.2 ± 0.6 for 60ER, 20ER, 10ER and 5ER, respectively.

First exercise bout. Whole body heat production and total heat loss during the first bout of exercise for the intermittent conditions compared with the corresponding time period of 60ER are presented in Fig. 1. Rate of metabolic heat production at the end of the first exercise bout was not significantly different when comparing 5ER to 60ER (P = 0.743) and 10ER to 60ER (P = 0.728). These similar rates of metabolic heat production were paralleled by similar rates of total heat loss, evaporative heat loss, and dry heat exchange between 5ER and 60ER as well as 10ER and 60ER (all, P > 0.05). However, rate of metabolic heat production was statistically greater at 20 min of exercise during 60ER compared with the end of the first exercise bout of 20ER (P ≤ 0.05). This was paralleled by greater rates of total and evaporative heat loss (P ≤ 0.05) but not of dry heat exchange (P = 0.843). Nonetheless, similar upper back SR between 5ER-60ER (0.48 ± 0.24 vs. 0.51 ± 0.24 mg·min⁻¹·cm⁻², P = 0.921), 10ER-60ER (0.86 ± 0.16 vs. 0.78 ± 0.30 mg·min⁻¹·cm⁻², P = 0.459), and 20ER-60ER (0.90 ± 0.34 vs. 0.96 ± 0.37 mg·min⁻¹·cm⁻², P = 0.085), as well as similar forearm SkBF between 5ER-60ER (45 ± 18 vs. 46 ± 20%, P = 0.704), 10ER-60ER (48 ± 21 vs. 51 ± 21%, P = 0.929), and 20ER-60ER (50 ± 13 vs. 52 ± 20%, P = 0.586). The thermal sensitivity of the evaporative heat loss and SkBF responses during the first exercise bout of each intermittent condition compared with the corresponding time period of 60ER are presented in Figs. 2 and 3, respectively. The sensitivity of the evaporative heat loss response was similar between 5ER-60ER (296 ± 96 vs. 344 ± 84 W/°C, P = 0.176), 10ER-60ER (376 ± 57 vs. 395 ± 51 W/°C, P = 0.685), and 20ER-60ER (535 ± 85 vs. 540 ± 94 W/°C, P = 0.890). Similarly, no significant differences in thermal sensitivity of the forearm SkBF response were observed between 5ER-60ER (49 ± 25 vs. 37 ± 10% max SkBF/°C, P = 0.913), 10ER-60ER (53 ± 9 vs. 36 ± 11% max SkBF/°C, P = 0.137), and 20ER-60ER (42 ± 22 vs. 34 ± 8% max SkBF/°C, P = 0.308).

Last exercise bout. Rates of metabolic heat production and total heat loss for each of the intermittent conditions compared with 60ER are presented in Fig. 4. Overall, rate of metabolic heat production during exercise did not differ between conditions (P = 0.581), averaging 660 ± 60 W, 642 ± 53 W, 646 ± 41 W, and 642 ± 29 W during 60ER, 20ER, 10ER, and 5ER, respectively (see Fig. 4). These workloads represented 55 ± 9% of the participants’ maximum oxygen uptake. The peak rate of total heat loss attained was significantly lower during each of the
Evaporative heat loss accounted for 100% of total heat loss for all conditions. Therefore, peak values of evaporative heat loss were also significantly greater during 60ER compared with intermittent conditions (P < 0.001, see Fig. 4).
with each intermittent condition ($P < 0.001$). There were also significant differences in dry heat exchange ($P \leq 0.05$) at the end of the last exercise bout. This was evidenced as a greater dry heat gain during 60ER compared with 10ER and 5ER.

Fig. 3. Forearm skin blood flow (SkBF) plotted as a function of esophageal temperature during the first exercise bout (Ex1) of intermittent exercise consisting of either 5-min (A; 5ER), 10-min (B; 10ER), or 20-min (C; 20ER) cycles compared with the corresponding time period of a 60-min continuous exercise condition (60ER). Values are means ± SE.

Fig. 4. Metabolic heat production (circles) and total heat loss (diamonds) during intermittent exercise consisting of either 5-min (A; 5ER), 10-min (B; 10ER), or 20-min (C; 20ER) exercise-rest cycles compared with a continuous condition consisting of 60-min exercise and 60 min of recovery (60ER). Values are means ± SE. *Significant difference ($P \leq 0.05$) between conditions.
Interestingly, peak values of forearm SkBF ($P = 0.633$) and upper back SR ($P = 0.574$) attained during 60ER (48 ± 24% and 1.11 ± 0.41 mg·min$^{-1}$·cm$^{-2}$) did not differ from those attained during 5ER (60 ± 14% and 0.92 ± 0.27 mg·min$^{-1}$·cm$^{-2}$), 10ER (48 ± 23% and 0.97 ± 0.17 mg·min$^{-1}$·cm$^{-2}$), and 20ER (39 ± 14% and 0.96 ± 0.32 mg·min$^{-1}$·cm$^{-2}$).

The differences between conditions in whole body heat exchange led to significantly different ($P \leq 0.05$) changes in body heat content over the exercise period(s) (Table 1). This was evidenced by a greater change in body heat content during 5ER and 10ER compared with 60ER ($P \leq 0.05$). The change in body heat content during exercise was reflected by increases in esophageal and rectal temperatures. Although there were no significant differences between conditions in the peak values attained for both esophageal ($P = 0.079$) and mean skin ($P = 0.309$, Table 2) temperatures, rectal temperature was significantly different between conditions ($P \leq 0.05$). This was evidenced by lower peak rectal temperatures during 5ER compared with 60ER ($P \leq 0.05$, Fig. 5). There was also a significant difference between conditions for heart rate at the end of the last exercise bout ($P \leq 0.05$) with peak heart rate values being lower during 5ER compared with 60ER ($P \leq 0.05$, Table 2). There were no significant differences ($P = 0.412$) in thermal sensation between conditions at the end of the last exercise bout, which averaged 2.8 ± 1.3, 2.9 ± 1.2, 2.5 ± 1.3, and 2.4 ± 1.2 during 60ER, 20ER, 10ER, and 5ER, respectively. However, peak ratings of perceived exertion were significantly different between conditions ($P \leq 0.05$). This was evidenced by lower ratings of perceived exertion during 5ER (12.0 ± 1.6) and 10ER (12.2 ± 1.6) compared with 60ER (13.3 ± 1.8), as well as during 5ER compared with 20ER (12.9 ± 1.9).

### End of experimental protocol

At the end of the experimental protocol, rate of metabolic heat production was statistically greater during 5ER compared with 60ER ($P \leq 0.05$), but not during 10ER and 20ER (both $P > 0.05$). There were also significant differences in the rate of total heat loss ($P < 0.001$), as it was still elevated during 5ER, 10ER, and 20ER, while it returned to near baseline values during 60ER (see Fig. 4). These differences in total heat loss were entirely due to differences in evaporative heat loss ($P < 0.001$), as there were no significant differences in rate of dry heat exchange ($P = 0.380$). Both forearm SkBF and upper back SR ($P = 0.117$) returned toward baseline values during 60ER (18 ± 5% and 0.38 ± 0.26 mg·min$^{-1}$·cm$^{-2}$) and did not differ from 10ER (21 ± 13% and 0.60 ± 0.28 mg·min$^{-1}$·cm$^{-2}$) and 20ER (19 ± 8% and 0.45 ± 0.31 mg·min$^{-1}$·cm$^{-2}$). However, forearm SkBF (36 ± 14%, $P \leq 0.05$), but not upper back SR (0.71 ± 0.29 mg·min$^{-1}$·cm$^{-2}$), remained significantly elevated at the end of
5ER compared with 60ER. The elevated rates of total heat loss during the recovery periods of the intermittent conditions led to significantly greater negative changes in body heat content over the recovery period(s) compared with 60ER ($P = 0.001$, see Table 1). However, there were no significant differences between conditions when examining the cumulative (60 min of exercise + 60 min of recovery) change in body heat content ($P = 0.583$, see Table 1). Similarly, there were no significant differences between conditions in esophageal ($P = 0.306$), rectal ($P = 0.072$), and mean skin ($P = 0.189$) temperatures, as well as for heart rate ($P = 0.704$), at the end of the experimental protocol (see Fig. 5 and Table 2). Finally, there were no significant differences ($P = 0.152$) in thermal sensation between conditions at the end of the experimental protocol, averaging $1.1 \pm 0.9$, $1.6 \pm 1.3$, $1.3 \pm 1.5$, and $1.2 \pm 1.0$ during 60ER, 20ER, 10ER, and 5ER, respectively.

Analysis 2: Comparisons Made Within a Given Intermittent Condition

Evaporative heat loss and dry heat exchange for each condition are presented in Fig. 6. Within each intermittent condition, rate of evaporative heat loss was significantly greater at the end of the last exercise bout compared with that measured at the end of the first exercise bout (all $P \leq 0.05$, see Fig. 6). Similarly, rate of dry heat exchange was significantly more negative (heat gain) at the end of the last exercise for each intermittent condition (all $P \leq 0.05$, see Fig. 6). The sensitivities of the evaporative heat loss and forearm SkBF responses for each exercise period within each intermittent condition are presented in Figs. 7 and 8, respectively. The sensitivity of the evaporative heat loss response did not significantly change from the first to the last exercise bout within 5ER ($296 \pm 96$ vs. $278 \pm 95$ W/°C, $P = 0.237$). However, the sensitivity of the evaporative heat loss response significantly increased from the first to the last exercise bout within 10ER ($376 \pm 57$ vs. $445 \pm 89$ W/°C, $P \leq 0.05$) and 20ER ($535 \pm 85$ vs. $588 \pm 28$ W/°C, $P \leq 0.05$). In contrast, no significant differences in thermal sensitivity of the forearm SkBF response were observed between the first and last exercise bout during 5ER (51 ± 23 vs. 54 ± 19% max SkBF/°C, $P = 0.848$), 10ER (53 ± 8 vs. 56 ± 21% max SkBF/°C, $P = 0.786$), and 20ER (44 ± 20 vs. 50 ± 27% max SkBF/°C, $P = 0.432$).

DISCUSSION

The novelty of the present study lies within the characterization of whole body and local heat loss responses, as well as evaluating the thermal sensitivity of the evaporative heat loss and forearm SkBF responses across different exercise-rest cycles. The main finding from the present study is that short-to-moderate duration exercise-rest cycles do not alter rates of whole body and local heat loss. Furthermore, the thermal sensitivities of the evaporative heat loss and forearm SkBF responses were not altered by multiple exercise-rest cycles. As such, similar cumulative changes in body heat content and core temperatures were observed at the end of the experimental protocol. These findings suggest that the greater core temperatures previously reported during intermittent exercise are not due to altered heat loss responses.
Studies that report greater increases in core temperature during intermittent exercise have attributed this response to either a lower rate of evaporative heat loss (4) or reduced SkBF (13, 17). Altered heat loss responses are a reasonable hypothesis to explain the greater core temperatures observed since evaporative heat loss during intermittent exercise has been shown to be modulated by nonthermal stimuli (11) and reduced.

Fig. 7. Evaporative heat loss plotted as a function of esophageal temperature during intermittent exercise consisting of either 5-min (A; 5ER), 10-min (B; 10ER), or 20-min (C; 20ER) exercise-rest cycles. Values are means ± SE.

Fig. 8. Forearm SkBF plotted as a function of esophageal temperature during intermittent exercise consisting of either 5-min (A; 5ER), 10-min (B; 10ER), or 20-min (C; 20ER) exercise-rest cycles. For clarity, exercise bouts 2 through 11 (Ex2–11) are represented as 1 for the 5ER condition. Values are means ± SE.

*Significant difference between the first and last exercise bouts. For clarity, exercise bouts 2 through 11 (Ex2–11) are represented as 1 for the 5ER condition.
SkBF may be associated with vasoconstriction accompanying the exercise-rest transients (8, 9). Based on the results from the present study, however, it is unlikely that alterations in either sweating and/or SkBF could explain the previously observed greater core temperatures during intermittent exercise. This is supported by: 1) unaltered rates of whole body and local heat loss responses, 2) similar thermal sensitivities of the evaporative heat loss and forearm SkBF responses, and 3) similar cumulative changes in body heat content.

Whole Body and Local Heat Loss Responses

Rate of total heat loss attained similar levels at the end of the first exercise bout during the intermittent conditions compared with the corresponding time point during the 60ER condition, implying that exercise of short duration itself does not modify whole body heat exchange. However, it must be noted that the peak levels of total heat loss attained during the intermittent conditions were not of the same magnitude as those attained during 60ER (see Fig. 4). This should not, however, be interpreted as an altered heat loss response. Rate of total heat loss has a time constant of ~10 min and can take up to 45 min to match rate of metabolic heat production (12). Since each intermittent condition contained exercise bouts shorter than 45 min, peak rates of total heat loss were never attained. Another argument against altered rates of total heat loss during the intermittent conditions is the fact that evaporative heat loss progressively increased with each exercise-rest cycle, being significantly greater at the end of the last exercise bout compared with the first exercise bout (see Fig. 6). This response appears to be a consistent finding with intermittent exercise (10, 11). Moreover, the local heat loss responses of SkBF and sweating did not differ between conditions at any of the time points compared; further supporting that intermittent exercise does not alter the body’s capacity to dissipate heat.

Thermal Sensitivities of the Evaporative Heat Loss and Forearm SkBF Responses

To our knowledge, this is the first study that examines the control of heat loss responses during intermittent exercise by evaluating the thermal sensitivity of the evaporative heat loss and forearm SkBF responses. We did not observe any differences in thermal sensitivities of each response during the first exercise bout of the intermittent conditions compared with the one measured during the corresponding time period of 60ER (see Figs. 2 and 3). These results suggest that the control of heat loss responses is not affected by exercise of short duration. Importantly, however, the thermal sensitivities of each response were not negatively altered across multiple exercise-rest cycles during the intermittent conditions (see Figs. 7 and 8). In fact, the thermal sensitivity of the evaporative heat loss response actually increased from the first to the last exercise bout during 10ER and 20ER. If intermittent exercise negatively altered the control of heat loss responses, it would be expected that the sensitivity of both responses would decrease from the first to the last exercise bout.

The significantly greater thermal sensitivity of the evaporative heat loss response during the last exercise bout of the 10ER and 20ER conditions also imply that evaporative heat loss increased to greater levels than can be explained by the progressively greater core temperatures. These results suggest that progressive increases in evaporative heat loss, consistently observed during intermittent exercise (10, 11), might be attributed to more than a “priming effect” associated with progressively greater core temperatures at the start of each exercise bout. It is possible that intermittent exercise may provide favorable peripheral and/or central adaptations in thermoeffector activity, and future studies should consider further examining this hypothesis.

Changes in Body Heat Content

When a single exercise bout is performed for a given amount of time and at a given rate of metabolic heat production, differences in body heat content between two conditions are dependent upon the rate at which total heat loss increases. In the present study, the rate of increase in total heat loss was similar between conditions, as determined by similar thermal sensitivities of the evaporative heat loss response, which accounted for 100% of total heat loss given the environmental conditions (i.e., 35°C, 20% relative humidity). As such, differences in body heat content in the present study were not due to different rates of increase in total heat loss. However, the exercise bouts were not fixed in duration. In this case, a shorter exercise bout will result in a smaller change in body heat content. This was evident in the present study, as the change in body heat content for a single exercise bout averaged 65 ± 9 kJ, 132 ± 22 kJ, 230 ± 35 kJ, and 550 ± 201 kJ during 5ER, 10ER, 20ER, and 60ER, respectively. Yet, although the change in body heat content per exercise bout was smallest during 5ER, it still demonstrated the greatest change in body heat content over the entire exercise period (see Table 1). These results suggest that, for a given rate of metabolic heat production and rate of increase in total heat loss, the change in body heat content is a function of the number of exercise cycles, with a greater number of cycles resulting in a greater change in body heat content.

In contrast, the negative change in body heat content during the recovery periods was greatest during the intermittent conditions compared with 60ER. The rate at which total heat loss decreases during a given recovery period of intermittent exercise has been shown to remain relatively constant across multiple exercise-rest cycles and to be similar to the rate observed following a single bout of exercise (10). As such, the same rationale explained above for exercise can be applied for the recovery period, with the overall negative change in body heat content dependent on the number of recovery cycles. The net effect was that the greater change in body heat content for the exercise component of the intermittent conditions was offset by the greater negative change in body heat content of the recovery component, resulting in similar cumulative changes in body heat content to the 60ER condition (Table 1).

Implications

Depending on the nature of occupational and military activities, the task to be performed can be completed in any one of four options: 1) set amount of work performed continuously for a set amount of time; 2) same amount of work as the first option, and in the same amount of time, but performed intermittently with short periods of high exertion levels separated by rest periods; 3) a lower amount of work can be performed intermittently at an exertion level midway between the first and...
second options; or 4) same amount of work as the first option but performed intermittently over a longer time period. In theory, the third and fourth options should be used if preventing exertional heat stress is the main concern. However, in some instances the nature of the occupation requires the use of the first two options. In any case, the ultimate objective of using exercise-rest cycles for most agencies is to ensure that core temperature does not exceed a threshold limit value (TLV) of 38°C (1, 18). Our findings provide interesting insight into the effectiveness of intermittent exercise in minimizing heat strain, specifically as it pertains to the fourth option. When exercise was performed continuously for 60 min (i.e., 60ER condition), peak values for rectal temperature rose above the TLV of 38°C (i.e., 38.17 ± 0.32°C), while they remained below the TLV during the 5ER (37.72 ± 0.34°C), 10ER (37.94 ± 0.32°C), and 20ER (37.93 ± 0.38°C) conditions. Furthermore, peak values for perceived exertion were significantly lower during the intermittent conditions. Therefore, when a given task does not have to be accomplished within a specific time frame, the use of exercise-rest cycles has practical implications by maintaining core temperature below the TLV and allows a given amount of work to be performed with less perceived exertional strain.

Perspectives and Significance

Since our findings suggest that thermoregulatory function is not altered by short-to-moderate duration exercise-rest cycles, the following question arises: what is responsible for the previously observed greater core temperatures during intermittent exercise (4, 13, 17)? One possibility relates to the fact that these studies employed exercise protocols that alternated between periods of high and low rates of metabolic heat production equal to the time-weighted average of the continuous condition. Although the average rate of metabolic heat production across each condition is similar using such an experimental protocol, it is possible that the heat stored during the short periods of high exertion is not completely offset during the recovery periods. Over the course of multiple exercise-rest cycles, this would result in a relatively greater cumulative change in body heat content during the intermittent condition, explaining the greater core temperatures observed. As the results from the present study suggest, this could occur in the presence of unaltered heat loss responses, with the number of exercise-rest cycles determining the overall change in body heat content. However, the present study did not directly test this hypothesis as we did not include a condition in which periods of high and low rates of metabolic heat production were alternated to elicit a similar time-weighted average to that of the continuous condition. As such, future studies should consider examining thermoregulatory responses between such a protocol and the one employed in the present study (i.e., fixed rate of metabolic heat production). Furthermore, while the present study focused on exercise-rest cycles that are more representative of an occupational setting, intermittent exercise is also characteristic of many athletic activities that may involve shorter exercise and/or rest transitions as well as more strenuous bouts of exercise. As such, it is unclear how our results may apply to exercise-rest cycles of very short duration (i.e., <5min) and of greater intensities. Further studies are required to examine this response. Finally, the present study was performed under compensable environmental conditions (i.e., warm and dry). Therefore, our results may not apply for conditions of uncompensable heat stress (e.g., with protective clothing).

Conclusion

In conclusion, the capacity to dissipate heat was not negatively altered by short-to-moderate duration exercise-rest cycles when exercise is performed at a fixed rate of metabolic heat production. This was evidenced by unaltered rates of whole body heat exchange, local heat loss responses, as well as thermal sensitivities of the evaporative heat loss and forearm SkBF responses. The net result was reflected by similar cumulative changes in body heat content and core temperatures. Therefore, our results confirm that intermittent exercise is an effective strategy to minimize the risk of exertional heat strain during occupational and military type activities.

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DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

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