Effects of Heat Acclimatization, Heat Acclimation, and Intermittent Exercise Heat Training on Time-Trial Performance

Yasuki Sekiguchi, PhD,* Courteney L. Benjamin, PhD, Ciara N. Manning, MS, Jeb F. Struder, MS, Lawrence E. Armstrong, PhD, Elaine C. Lee, PhD, and Douglas J. Casa, PhD

Background: The purpose of this study was to investigate effects of heat acclimatization (HAz) followed by heat acclimation (HA), and intermittent heat training (IHT) on time-trial performance.

Hypothesis: Time-trial performance will improve after HA and will further improve with twice a week of IHT.

Study Design: Interventional study.

Level of Evidence: Level 3.

Methods: A total of 26 male athletes (mean ± SD; age, 35 ± 12 years; body mass, 72.8 ± 8.9 kg; peak oxygen consumption [VO_{2peak}], 57.3 ± 6.7 $mL \cdot kg^{-1} \cdot min^{-1}$) completed five 4-km time trials (baseline, post-HAz, post-HA, post-IHT4, post-IHT8) in the heat (ambient temperature, 35.4°C ± 0.3°C; relative humidity, 46.7% ± 1.2%) on a motorized treadmill. After baseline time trial, participants performed HAz (109 ± 10 days) followed by post-HAz time trial. Then, participants completed 5 days of HA, which involved exercising to induce hyperthermia (38.50°C-39.75°C) for 60 minutes. Participants were then divided into 3 groups and completed IHT either twice per week (IHT_{MAX}), once per week (IHT_{MIN}), or not at all (IHT_{CON}) over an 8-week period. The exercise used for the IHT matched the HA. Four-kilometer time trials were performed after 4 weeks (post-IHT4) and 8 weeks of IHT (post-IHT8).

Results: Time trial was faster in post-HA (17.98 ± 2.51 minutes) compared with baseline (18.61 ± 3.06 minutes; $P = 0.037$) and post-HAz (18.66 ± 3.12 minutes; $P = 0.023$). Percentage change in time trial was faster in IHT_{MAX} (−3.9% ± 5.2%) compared with IHT_{CON} (11.5% ± 16.9%) ($P = 0.020$) and approached statistical significance with large effect (effect size = 0.96) compared with IHT_{MIN} (1.6% ± 6.2%; $P = 0.059$) at post-IHT8. Additionally, IHT_{MAX} (−2.2% ± 4.2%) was faster than IHT_{CON} (3.6% ± 6.9%) ($P = 0.05$) at post-IHT4.

Conclusion: These results indicate that HA after HAz induces additional improvement in time-trial performance. IHT twice per week shows improvement after 8 weeks, while once per week maintains performance for 8 weeks. No IHT results in a loss of adaptations after 4 weeks and even greater losses after 8 weeks.

Clinical Relevance: HA after HAz improves time-trial performance, twice a week of IHT improves performance further, and once a week of IHT maintains performance for at least 8 weeks.

Keywords: heat exposure; thermoregulation; endurance performance; heat adaptation; environmental stress

Sport scientists, coaches, and medical professionals are repeatedly given the task of preparing athletes for competition within a wide range of environmental conditions, including exercise in the heat. Major sport events at both national (ie, National Collegiate Athletic Association) and international levels (ie, the FIFA World Cup, the World

*Address correspondence to Yasuki Sekiguchi, PhD, Department of Kinesiology and Sport Management, Texas Tech University, 3204 Main Street, Box 4301, Lubbock, TX 79409 (email: yasuki.sekiguchi@ttu.edu) (Twitter: @YasukiSekiguchi).
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Championship, and the Olympics) are often held in locations where heat may have a detrimental effect on athletic performance. It is well-known that training and competing in the heat leads to greater physiological strains, including higher heart rate (HR) and internal body temperature.[29]

Physiological strain can lead to higher fatigue levels and lower exercise performance during exercise in the heat.[15,18] Indeed, during the Union Cycliste Internationale Road World Championships of 2016, 85% of elite cyclists reportedly reached an internal body temperature of at least 39°C with 25% exceeding 40°C.[24] Greater levels of hyperthermia are known to be associated with higher perceived fatigue.[15] In addition to the effect of heat on performance, excessive heat exposure also poses an increased risk for heat illness.[5] These outcomes stress the importance of implementing practical and effective heat mitigation strategies for both the safety and optimal performance of athletes.

Heat acclimation (HA) and heat acclimatization (HAz) are documented as important heat mitigation strategies that affect athlete performance and readiness during exercising in the heat.[1] HA refers to training in a hot artificial environment while HAz refers to outdoor training in a hot environment. Both HA and HAz are the process of systematic and repeated heat exposures, which induce key physiological and protective adaptations. Adaptations include decreases in HR, internal body temperature, skin temperature, rating of perceived exertion (RPE), and sweat sodium and chloride concentrations, as well as increases in plasma volume and sweat rate.[4,29] These adaptations collectively enhance exercise performance in a hot environment by improving the body's thermoregulatory efficiency while decreasing the overall physiological strain.[20]

A recent meta-analysis examined the magnitude of performance change and factors contributing to those changes after HA.[7] The largest performance enhancement was observed in time to exhaustion (effect size [ES] = 0.86) followed by time trial (ES = 0.49), mean power (ES = 0.37), maximal oxygen consumption (VO_{2max}) (ES = 0.30), and peak power (ES = 0.29).[7] Most of the studies examining exercise performance reported using a variation of a HA protocol, rather than HAz. While the controlled nature of HA may result in greater adaptations, HAz may be more widely accessible and feasible. However, when environmental conditions are mild such as the summer in New England in the United States, large adaptations might not be observed.[3] In this situation, the use of both HAz and HA might be beneficial since athletes perform their normal training during the summer, and HA might be able to induce additional adaptations. No study to date has examined the combined impact of HA after a period of HAz for the purposes of achieving optimal physiological adaptations and enhanced exercise performance.

Adaptations, induced by HAz or HA, can also diminish over time if not properly maintained. When an individual discontinues heat exposure, physiological and performance adaptations typically fade over time. While data regarding decay are limited, performance enhancements after HA seem to only persist for approximately 1 to 2 weeks without further heat exposure.[12] Decay is arguably the largest obstacle to overcome when HA is implemented in sport settings. Only 1 study has investigated the maintenance of benefits in physiological variables for an extended period of time after HA, with the implementation of intermittent heat training (IHT).[23] However, the effect of IHT on exercise performance was not investigated. Examining the methods for maintaining adaptations after HA is critical for maximizing the performance without interfering with sport-specific training and imposing undue stress onto the body. Thus, the purposes of this study were (1) to investigate the effect of HA after HAz on time-trial performance, (2) to examine the effect of IHT on time-trial performance, and (3) to determine the factors associated with improvement of performance after HAz and HA in male endurance-trained athletes.

METHODS

Thirty-eight male participants were recruited in this study, and 10 participants dropped the study after summer training and 1 participant dropped at week 4 of IHT because of scheduling. Data from 1 person were excluded from the analysis because of data reliability. Therefore, 26 male endurance athletes (mean ± SD age, 35 ± 12 years; body mass, 72.8 ± 8.9 kg; height, 178.7 ± 6.3 cm; VO_{2peak}, 57.3 ± 6.7 $ml \cdot kg^{-1} \cdot min^{-1}$; % body fat (%BF), 10.8% ± 5.1%) completed this study and were included in this research. These endurance athletes had been performing 8.3 hours of endurance training (run, bike, and swim), 1.9 hours of strength, and 2.7 hours of cross-training on average per week when they started participating in this study. After an explanation of study procedures, which was approved by the institutional review board at the University of Connecticut, participants provided written and informed consent to participate in this study. This study occurred in Connecticut, USA.

The study timeline is described in Figure 1. Initially, participants performed a VO_{2peak} test that involved graded running exercise on a motorized treadmill (T150; COSMED) to measure VO_{2peak} and the velocity of VO_{2peak} (vVO_{2peak}) at the beginning of the study in a thermoneutral environment (ambient temperature [T_{amb}], 20°C; relative humidity [%RH] 30%). Based on the volume of expired air, carbon dioxide consumption (VCO_2), VO_2, and the speed at VO_2, ventilatory threshold (VT) was calculated for each test. The participants completed 5 minutes of a self-selected pace warm-up before beginning the test. During the test, the speed was increased either 0.8 or 1.6 $km \cdot h^{-1}$ (0.5 or 1.0 $mile \cdot h^{-1}$) after each 2-minute stage and continued until reaching volitional fatigue. VO_{2peak} was also measured at approximately 1 week before post-HAz, post-IHT4, and post-IHT8, as well as 1 week after post-HA to monitor aerobic fitness changes.

The baseline trial occurred in May and early June, prior to any heat exposure occurring in the laboratory or outside environment. It is important to note that this research was part of a large study in which participants completed 60 minutes of exercise at 58.8% ± 2.6% vVO_{2peak} on a treadmill in the heat (T_{amb}, 35.4°C ± 0.3°C; %RH, 46.7% ± 1.2%; wet bulb globe

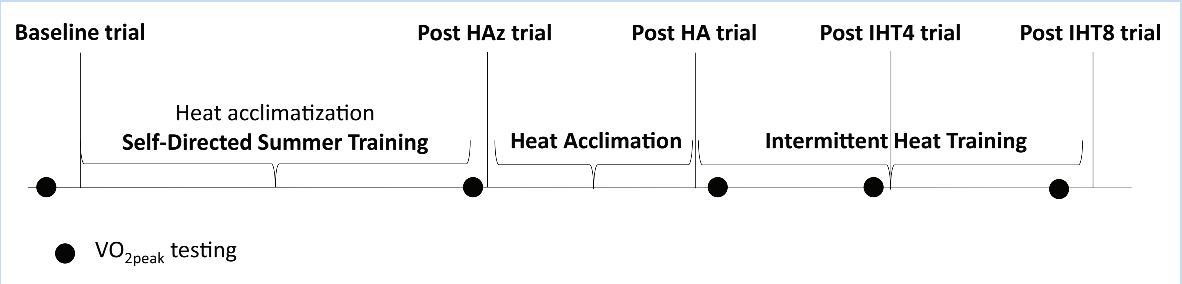

Figure 1. Study timeline. HA, heat acclimation; HAz, heat acclimatization; IHT, intermittent heat training. VO_{2peak}, peak oxygen consumption.

temperature [WBGT], 29.3°C ± 0.2°C; wind speed 6.4 ± 0.2 $km \cdot h^{-1}$) before the 4-km time trial. On arrival, participants provided urine samples for assessment of their hydration status to ensure they began the 60 minutes of exercise in a euhydrated state (urine-specific gravity, 1.009 ± 0.004; color, 2 ± 1).[2] After 60 minutes of exercise, a minimum of 30 minutes rest (34.4 ± 7.2 minutes) was provided to replace fluid loss from 60 minutes of exercise and to ensure participants started the 4-km time trial <1% body mass loss (baseline, 0.61% ± 0.26%; post-HAz, 0.58% ± 0.33%; post-HA, 0.73% ± 0.33%; post-IHT4, 0.78% ± 0.20%; post-IHT8, 0.64% ± 0.34%). Rectal temperature (T_{rec}) also decreased during this period (baseline, 37.51°C ± 0.28°C; post-HAz, 37.42°C ± 0.39°C; post-HA, 37.25°C ± 0.36°C; post-HT4, 37.34°C ± 0.30°C; post-HT8, 37.46°C ± 0.31°C), before starting the 4-km time trial, as recommended by previous research.[6,27] During the 4-km time trial, T_{rec} (MP160; BIOPAC Systems Inc) and HR (H10, Polar Electro) were collected every 1 km. Additionally, RPE on a 6 to 20 Likert-type scale,[10] thermal sensation on a 0 to 8.0 Likert-type scale,[30] and fatigue level on a 0 to 10 Likert-type scale were measured before and after the 4-km time trial.

After baseline time trial, participants completed self-directed summer training (HAz), which occurred for 109 ± 10 days. Training loads, including total distance covered, training time, and average HR, were monitored by the device of the participants' preference. T_{amb}, %RH, heat index (HI), and WBGT were reported for each session. Daytime WBGTs (7 AM to 7 PM) were modeled using Heat Stress Adviser software package (Version 2005; Zunis Foundation).[11,16]

After HAz, participants completed the second identical trial of 60 minutes of exercise followed by the 4-km time trial (post-HAz). This occurred in late August and early September. After post-HAz, participants performed 5 days of HA over 8 days in an artificially hot environment (T_{amb}, 39.1°C ± 0.5°C; %RH, 51.1% ± 2.5%; WBGT, 33.2°C ± 0.8°C). During the HA sessions, participants exercised to achieve hyperthermia (defined as 38.50°C and 39.75°C) for 60 minutes, which HA induction method is defined as "hyperthermic zone HA." Participants started HA sessions with a higher intensity exercise (~70% vVO_{2peak}) to increase T_{rec} rapidly to 38.5°C and continued to exercise the remaining 60 minutes with adjusted intensity in order to maintain T_{rec} in hyperthermic zone (38.50°C and 39.75°C). After the 5 sessions of HA, the same trial was performed to investigate adaptations after HA.

After HA, participants were randomly assigned to 3 groups, which included the maximal IHT group (IHT_{MAX}, n = 9), the minimum IHT group (IHT_{MIN}, n = 9), and the control group (IHT_{CON}, n = 8). Groups were matched for VO_{2peak} (IHT_{CON}, 58.6 ± 4.7 $mL \cdot kg^{-1} \cdot min^{-1}$; IHT_{MIN}, 58.1 ± 9.7 $mL \cdot kg^{-1} \cdot min^{-1}$; IHT_{MAX}, 55.5 ± 4.8 $mL \cdot kg^{-1} \cdot min^{-1}$; $P = 0.604$), body mass (IHT_{CON}, 72.0 ± 9.8 kg; IHT_{MIN}, 72.4 ± 7.2 kg; IHT_{MAX}, 73.98 ± 10.5 kg; $P = 0.911$), and age (IHT_{CON}, 33 ± 8 years; IHT_{MIN}, 34 ± 13 years; IHT_{MAX}, 38 ± 15 years; $P = 0.653$). IHT_{MAX} completed a total of 16 IHT sessions (twice per week) and IHT_{MIN} completed a total of 8 IHT sessions (once per week) over the course of 8 weeks. IHT_{CON} did not perform any IHT over the same 8 weeks. The number of days between IHT sessions for IHT_{MAX} was 3.6 ± 1.4 days and IHT_{MIN} was 7.0 ± 2.2 days. The exercise protocol used for the IHT matched the HA sessions. To assess the effectiveness of IHT, participants performed the 4-km time trial after 4 weeks (post-IHT4) and 8 weeks (post-IHT8) of IHT. Participants were instructed to perform their normal training outside the laboratory during this period and their training loads were monitored.

The percentage change in 4-km time trial during IHT phases was calculated based on the time post-HA to examine the impacts of IHT. Percentage change was used to minimize differences between groups and individual variability in time-trial performance at the beginning of the IHT period while there were no differences in time trial between groups at post-IHA ($P = 0.800$). Repeated-measures analyses of variance with post hoc of least significant difference were used to assess differences in 4-km time-trial performance, the changes in training (inclusive of both inside and outside the artificial environment), HR, T_{rec}, RPE, thermal sensation, and fatigue level, at baseline, post-HAz, and post-HA, and independent and dependent *t* tests were performed to assess the differences at post-HA, post-IHT4, and post-IHT8.[28] ES was calculated using Hedges' *g* with the resulting effects identified as either small (0.2-0.49), medium (0.5-0.79), or large (>0.8) effects.[19] Data are reported as M ± SD, 95% CIs, and ES.

Stepwise linear regression was used to predict 4-km time-trial performance improvement, which was defined as the differences in 4-km time between pre- and posttrials. VO_{2peak}, VT change, weekly distance (km), sum of weekly distance (km), weekly training time (minutes), average HR (bpm), WBGT, T_{amb}, %RH, and HI during HAz were used to predict performance improvement at post-HAz. Area under the curve of T_{rec} (AUC) and area under the curve of T_{rec} above 38.5°C ($AUC^{38.5}$) were calculated by the integral of T_{rec} during HA sessions. AUC, $AUC^{38.5}$, average HR, the amount of sweat during HA induction, VO_{2peak}, VT change, %BF, age, body mass, and 4-km time at post-HAz were utilized to predict performance improvement for post-HA trial. Additionally, independent *t* tests were performed to examine the differences between variables that improved 4-km time trial (Improved) and those that did not (Not-improved). All statistical analyses were completed using SPSS Statistics for Mac, Version 25 (IBM Corp). Significance was set at $P \leq 0.05$.

RESULTS

During each HAz session, average training duration was (M ± SD) 59.64 ± 83.42 minutes for running and 94.49 ± 71.14 minutes for cycling and average HR was 139 ± 15 bpm for running and 128 ± 16 bpm for cycling. Also, average WBGT was 22.34°C ± 4.27°C and 23.74°C ± 4.04°C for running and cycling, respectively. For HA sessions, the average duration was 82 ± 5 minutes (day 1, 81 ± 7 minutes; day 2, 81 ± 6 minutes; day 3, 84 ± 6 minutes; day 4, 83 ± 8 minutes; day 5, 82 ± 8 minutes). The overall average T_{rec} was 38.83°C ± 0.24°C for the entire session (day 1, 38.83°C ± 0.40°C; day 2, 38.91°C ± 0.30°C; day 3, 38.79°C ± 0.34°C; day 4, 38.80°C ± 0.29°C; day 5, 38.81°C ± 0.32°C). The overall average T_{rec} for the hyperthermic period was 39.16°C ± 0.17°C (day 1, 39.13°C ± 0.42°C; day 2, 39.24°C ± 0.22°C; day 3, 39.14°C ± 0.35°C; day 4, 39.17°C ± 0.29°C; day 5, 39.14°C ± 0.22°C). Also, the overall average HR was 134 ± 11 bpm (day 1, 137 ± 13 bpm; day 2, 134 ± 14 bpm; day 3, 133 ± 11 bpm; day 4, 132 ± 13 bpm; day 5, 132 ± 13 bpm) for the entire session and 134 ± 12 bpm (day 1, 138 ± 14 bpm; day 2, 134 ± 15 bpm; day 3, 132 ± 13 bpm; day 4, 133 ± 14 bpm; day 5, 131 ± 12 bpm) for the hyperthermic period.

As reported in previous literature,[8] average HR during 60 minutes exercise at post-HA (136 ± 11 bpm) was lower than post-HAz (140 ± 14 bpm; $P = 0.003$) and baseline (144 ± 12 bpm; $P < 0.001$), and post-HAz was lower than baseline ($P = 0.004$). Also, average T_{rec} during 60 minutes exercise at post-HA (38.07°C ± 0.40°C) was lower than post-HAz (38.31°C ± 0.45°C; $P = 0.004$) and baseline (38.34°C ± 0.40°C; $P = 0.002$). Sweat rate at post-HA (2.0 ± 0.6 $L \cdot h^{-1}$) was higher than post-HAz (1.7 ± 0.4 $L \cdot h^{-1}$) ($P = 0.036$). There were no differences in VO_{2peak} throughout this study (baseline, 57.3 ± 6.7 $mL \cdot kg^{-1} \cdot min^{-1}$; post-HAz, 58.9 ± 8.4 $mL \cdot kg^{-1} \cdot min^{-1}$; post-HA, 58.6 ± 7.2 $mL \cdot kg^{-1} \cdot min^{-1}$; post-IHT4, 59.7 ± 7.8 $mL \cdot kg^{-1} \cdot min^{-1}$; post-IHT8, 59.4 ± 8.9 $mL \cdot kg^{-1} \cdot min^{-1}$; $P = 0.141$). Additionally, vVO_{2peak} was not changed over the course of the study (baseline, 16.1 ± 1.6 $km \cdot h^{-1}$; post-HAz, 15.8 ± 1.8 $km \cdot h^{-1}$; post-HA, 16.1 ± 1.6 $km \cdot h^{-1}$; post-IHT4, 16.1 ± 1.4 $km \cdot h^{-1}$; post-IHT8, 15.9 ± 1.8 $km \cdot h^{-1}$; $P = 0.616$).

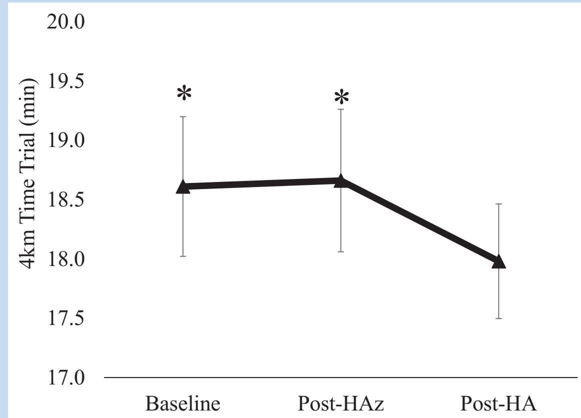

Figure 2. Four-kilometer time-trial performance at baseline, post–heat acclimatization (Post-HAz), and post–heat acclimation (Post-HA). *Indicates statistical significance from post-HA, $P \leq 0.05$.

Heat Acclimatization Did Not, but Subsequent 5-Day Heat Acclimation Did Improve 4-km Time-Trial Performance

Time trial was significantly faster at post-HA (M ± SD; 17.98 ± 2.51 minutes) compared with both baseline (M ± SD [95% CI], 18.61 ± 3.06 minutes [−1.23, −0.04]; ES = 0.23; $P = 0.037$) and post-HAz (18.66 ± 3.12 minutes [−1.27, −0.10]; ES = 0.24; $P = 0.023$) (Figure 2). However, there was no difference in time-trial performance between baseline and post-HAz ($P = 0.894$).

Heat Acclimation Also Improved RPE, Thermal Sensation, and Fatigue Levels

There were no differences in HR ($P = 0.146$) and T_{rec} ($P = 0.061$) at the end of the 4-km time trial between baseline (HR, 181 ± 13 bpm; T_{rec}, 38.82°C ± 0.52°C), post-HAz (HR, 177 ± 16 bpm; T_{rec}, 38.81°C ± 0.45°C), and post-HA (HR, 178 ± 12 bpm; T_{rec}, 38.63°C ± 0.49°C). At the end of 4 km, RPE, thermal sensation, and fatigue level were lower at post-HA (RPE, 16 ± 3; thermal sensation, 6.1 ± 0.8; fatigue, 5 ± 2) compared with baseline (RPE, 18 ± 3 [−4, −0.4], ES = 0.67, $P = 0.018$; thermal sensation, 6.9 ± 0.6 [−1.1, −0.5], ES = 1.13, $P < 0.001$; fatigue, 7 ± 2 [−3, −1], ES = 1.00, $P < 0.001$). Also, thermal sensation and fatigue were lower at post-HA compared with post-HAz (thermal sensation, 6.6 ± 0.7 [−0.8, −0.3], ES = 0.67, $P < 0.001$; fatigue, 7 ± 2 [−3, −1], ES = 1.00, $P < 0.001$). Furthermore, thermal sensation at post-HAz was lower than baseline ([−0.5, −0.1]; ES = 0.46; $P = 0.010$).

IHT Performed Twice per Week Induced Better 4-km Time-Trial Performance Than Once per Week and No IHT Over 8 Weeks

Percentage change in time trial was significantly faster in IHT_{MAX} (−3.9% ± 5.2%) compared with IHT_{CON} (11.5% ± 16.9% [−28.0, −2.7]; ES = 1.27; $P = 0.020$) and approached statistical significance with large effect compared with IHT_{MIN} (1.6% ± 6.2% [−11.2, 0.2]; ES = 0.96; $P = 0.059$) at post-IHT8 (Figure 3).

Table 1. Four-kilometer time, HR, T_{rec}, RPE, thermal sensation, and fatigue level at the end of 4-km time trial between IHT_{CON} (no intermittent heat training), IHT_{MIN} (once per week intermittent heat training), and IHT_{MAX} (twice per week intermittent heat training) at post-HA, post-IHT4, and post-IHT8[a]

		4-km Time, min	HR, bpm	T_{rec}, °C	RPE	Thermal Sensation	Fatigue
Post-HA	IHT_{CON}	17.33 ± 2.34	181 ± 11	38.5 ± 0.4	17 ± 3	6.1 ± 0.8	6 ± 3
	IHT_{MIN}	17.90 ± 3.33	177 ± 13	38.6 ± 0.6	16 ± 4	6.1 ± 0.8	5 ± 2
	IHT_{MAX}	18.63 ± 1.69	176 ± 14	38.8 ± 0.5	16 ± 4	6.2 ± 0.7	5 ± 1
Post-IHT4	IHT_{CON}	18.03 ± 3.26	185 ± 14	38.5 ± 0.4	16 ± 4	5.9 ± 1.0	7 ± 3
	IHT_{MIN}	17.94 ± 2.98	180 ± 10	38.6 ± 0.4	18 ± 2	6.2 ± 0.8	6 ± 2
	IHT_{MAX}	18.17 ± 1.02	179 ± 17	38.7 ± 0.3	17 ± 2	6.0 ± 1.3	5 ± 2
Post-IHT8	IHT_{CON}	19.44 ± 4.79	185 ± 14	38.6 ± 0.3	17 ± 2	6.6 ± 1.2	8 ± 2
	IHT_{MIN}	18.02 ± 2.26	184 ± 8	38.8 ± 0.5	17 ± 2	6.1 ± 0.9	6 ± 2
	IHT_{MAX}	17.87 ± 1.41	180 ± 16	38.6 ± 0.4	18 ± 2	6.1 ± 1.0	5 ± 2

[a]Data are presented as mean ± SD. HR, heart rate; Trec, rectal temperature; RPE, rating of perceived exertion; IHTCON, control group; IHTMIN, minimum intermittent heat training group; IHTMAX, maximal intermittent heat training group; post-HA, post-heat acclimation; post-IHT4, post-week 4 of intermittent heat training; post-IHT8, post-week 8 of intermittent heat training.

Additionally, IHT_{MAX} (−2.2% ± 4.2%) was significantly faster than IHT_{CON} (3.6% ± 6.9% [−11.7, −0.03]; ES = 1.03; P = 0.05) at post-IHT4. There were no differences between IHT_{MAX}, IHT_{MIN}, and IHT_{CON} at the end of 4 km in HR (P = 0.711), T_{rec} (P = 0.277), RPE (P = 0.552), thermal sensation (P = 0.100), and fatigue levels (P = 0.204) (Table 1).

IHT Twice per Week Improved, Once per Week Maintained, and No IHT Decreased 4-km Time-Trial Performance After 4 to 8 Weeks Despite Normal Training

Percent change in time trial in IHT_{MAX} at post-HT8 (−3.9% ± 5.2%) was faster than post-HA (0% [−7.9, 0.1], ES = 1.06, P = 0.056) while approaching statistical significance with large effect. There were no differences in IHT_{MIN} between post-HA (0%), post-IHT4 (0.6% ± 5.6%), and post-IHT8 (1.6% ± 6.2%). While there was no statistically significant difference, IHT_{CON} at post-HA was observed to be faster than post-IHT4 (3.6% ± 6.9%) and post-IHT8 (11.5% ± 16.9%) and demonstrated a moderate effect (ES = 0.74) and a large effect (ES = 0.96), respectively.

Total Training Volume Did Not Change Throughout the Study and WBGT Was Lower During IHT

There were no differences in training time, including training both inside and outside the laboratory between IHT_{MAX} (HAz, 68 ± 25 minutes; IHT weeks 1-4, 79 ± 33 minutes, IHT weeks 5-8, 64 ± 25 minutes), IHT_{MIN} (HAz, 62 ± 10 minutes; IHT weeks 1-4, 52 ± 9 minutes, IHT weeks 5-8, 49 ± 10 minutes), and IHT_{CON} (HAz, 61 ± 28 minutes; IHT weeks 1-4, 57 ± 34 minutes; IHT weeks 5-8, 53 ± 27 min) (P = 0.663). WBGT was lower during IHT weeks 5 to 8 (9.4°C ± 3.1°C) than HAz (23°C ± 1°C) and IHT weeks 1 to 4 (15°C ± 3°C) (P < 0.001). However,

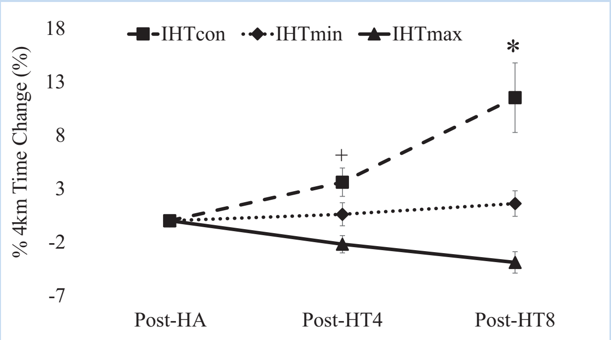

Figure 3. Percentage 4-km time change in post-IHT4 and post-IHT8 from post–heat acclimation (HA). Post-IHT4, week 4 of intermittent heat training; post-IHT8, week 8 of intermittent heat training; IHT_{MAX}, twice per week intermittent heat training group; IHT_{MIN}, once per week intermittent heat training group; IHT_{CON}, control group. *Indicates statistical significance from IHT_{MAX} at post-IHT8, +indicates statistical significance from IHT_{MAX} at post-IHT4; $P \leq 0.05$.

there were no differences in WBGT between groups at any time points ($P = 0.152$).

Factors of Heat Acclimatization That Influenced Improvements in 4-km Time-Trial Performance

Summer training performed within conditions of higher %RH significantly predicted the larger improvement in time-trial performance at post-HAz ($r^2 = 0.244$; $P = 0.014$). Additionally, %RH (Improved, 68.6% ± 8.5%; Not-improved, 61.9% ± 5.4%; ES = 0.98; $P = 0.028$) was significantly higher for participants who improved time trial at post-HAz. VO_{2peak} (Improved, 53.5 ± 5.5 $mL \cdot kg^{-1} \cdot min^{-1}$; Not-improved, 59.7 ± 6.9 $mL \cdot kg^{-1} \cdot min^{-1}$; ES = 0.97; $P = 0.028$), T_{amb} (Improved, 22.2°C ± 1.8°C; Not-improved, 23.6°C ± 1.5°C; ES = 0.86; $P = 0.05$), and WBGT (Improved, 22.0°C ± 1.5°C; Not-improved, 23.1°C ± 1.1°C; ES = 0.86; $P = 0.041$) were significantly lower for participants who improved time trial at post-HAz. There were no differences in weekly average distance (Improved, 39.2 ± 25.0 km; Not-improved, 43.3 ± 32.4 km; ES = 0.14; $P = 0.739$), sum of weekly distance (Improved, 344.5 ± 176.6 km; Not-improved, 393.0 ± 138.4 km; ES = 0.31; $P = 0.458$), average training time (Improved, 69.4 ± 25.7 minutes; Not-improved, 62.7 ± 21.5 minutes; ES = 0.29; $P = 0.499$), average HR (Improved, 133 ± 11 bpm; Not-improved, 137 ± 11 bpm; ES = 0.36; $P = 0.428$), and HI (Improved, 29.9°C ± 1.2°C; Not-improved, 30.0°C ± 0.8°C; ES = 0.10; $P = 0.853$) between participants who improved and did not improve time trial.

Factors of Heat Acclimation That Influenced Improvements in 4-km Time-Trial Performance

Slower time trial at post-HAz significantly predicted larger improvement at post-HA ($r^2 = 0.376$; $P = 0.001$), and younger age plus slower time trial at post-HAz predicted larger variances ($r^2 = 0.583$; $P < 0.001$). There were no differences in $AUC^{38.5}$ (Improved, 218.4°C·min ± 32.5°C·min; Not-improved, 197.6°C·min ± 51.9°C·min; ES = 0.56; $P = 0.242$), AUC (Improved, 15399.3°C·min; ± 904.2°C·min; Not improved, 16027.7°C·min ± 716.9°C·min; ES = 0.68; $P = 0.160$), average HR (Improved, 134 ± 12 bpm; Not-improved, 133 ± 8 bpm; ES = 0.09; $P = 0.969$), the amount of sweat (Improved, 2.56 ± 0.57 L; Not-improved, 2.51 ± 0.45 L; ES = 0.04; $P = 0.921$), VO_{2peak} (Improved, 59.3 ± 8.3 $mL \cdot kg^{-1} \cdot min^{-1}$; Not-improved, 57.7 ± 9.3 $mL \cdot kg^{-1} \cdot min^{-1}$; ES = 0.02; $P = 0.678$), %BF (Improved, 10.8% ± 5.0%; Not-improved, 10.9% ± 6.0%; ES = 0.02; $P = 0.979$), age (Improved, 33 ± 11 y; Not-improved, 41 ± 16 y; ES = 0.66; $P = 0.198$), and body mass (Improved, 73.4 ± 8.6 kg; Not-improved, 71.1 ± 10.1 kg; ES = 0.26; $P = 0.580$) between participants who improved and did not improve time trial.

DISCUSSION

This study was initiated to investigate the effects of HA after HAz and subsequent IHT on 4-km time-trial performance in addition to identifying factors potentially associated with improvement of performance after HAz and HA in male endurance-trained athletes. This study was one of the longest HAz, HA, and IHT research studies, which provided critical data that can be used in practical sport settings. A review of the results showed that time-trial performance after HA was significantly faster than both baseline and after HAz, while there was no difference between baseline and after HAz. Furthermore, IHT twice per week was faster than once per week and no IHT. This study added important information to the previously established literature, with improvements in endurance performance resulting from the inclusion of HA after HAz and IHT.

HAz did not improve 4-km time-trial performance in this study. Even though higher %RH during summer training predicted improvements in performance, the environmental conditions participants experienced during this training period may not have been great enough to provide a stress to induce beneficial adaptations. As a previous study indicated,[17] the improvement of endurance performance after HAz requires severe environmental conditions, therefore, mild environmental conditions might not be enough to induce performance adaptations. However, in contrast to HAz results, a short-term HA after HAz induced improvement in 4-km time-trial performance. HAz has been referred to as a less controlled protocol compared with HA, and the level of adaptation is different between cases while HAz may be more widely accessible.[3,25] Therefore, depending on the severity of environmental conditions, summer training might not induce adequate performance adaptations. In this case, adding short-term HA can induce additional performance improvements, which can make this method more attractive to athletes who perform summer training regardless.

Time-trial performance after HA was 41 seconds faster than an unacclimatized state, and 40 seconds faster than after HAz. In addition to faster time-trial performance, RPE, thermal sensation, and fatigue levels were also lower at the end of time trial. These perceptual adaptations were observed even though athletes ran at the faster pace. The magnitude of improvement observed in this study was larger than the 4-second improvement seen in a 2-km time trial after 5 days of isothermal (38.5°C) HA completed in a previous study with trained individuals.[13] The thermal load induced by the heat exposures in the current study may provide one potential explanation for this difference in performance adaptation as explained by the $AUC^{38.5}$. The current study utilized the hyperthermic zone HA method to induce HA, which resulted in greater levels of hyperthermia than the isothermal method previously implemented.[13] Greater hyperthermia might be necessary to induce adaptations that result in larger performance adaptations; however, further investigation is needed.[22]

IHT_{MAX} was faster than IHT_{CON} ($P = 0.020$) and IHT_{MIN} at post-IHT8 with a large effect ($P = 0.059$). These results indicate that IHT twice per week demonstrates improvements in time-trial performance 8 weeks after HA. There were no differences in time-trial performance between post-HA, post-IHT4, and post-IHT8 in IHT_{MIN}, and once per week of IHT may hold adaptations for 8 weeks. Furthermore, HT_{CON} demonstrated a loss of adaptation and decreased performance at 4 weeks with even greater decrements after 8 weeks. Decay in exercise performance has been previously investigated with 1 study demonstrating time to exhaustion was shorter 1 week (13.7 minutes) and 2 weeks (12.7 minutes) after HA compared with immediately after HA (14.2 minutes).[14] Even though there is no previous research examining a decay after HA in time-trial performance, limited data show that improvements in performance persist for 1 to 2 weeks without heat exposures.[12] These results are consistent with the current study, which indicates that no IHT led to loss of performance adaptations in 4 weeks.

While there was no previous study investigating the effects of IHT on performance, a few studies examined physiological adaptations. One previous study indicated that heat exposures completed once every 5 days for 25 days led to a 0.47°C lower T_{rec} and 28 bpm lower HR with 60 minutes of steady-state exercise within a hot environment, indicating the potential benefits of implementing IHT.[23] Additionally, the current study was a part of a large study, and physiological adaptations in HR, T_{rec}, and skin temperature during 60 minutes of exercise resulted from HAz and HA did not show significant losses with IHT twice (HT_{MAX}) and once (HT_{MIN}) with 8 weeks of IHT. These physiological adaptations might contribute to performance improvements derived from IHT twice per week for 8 weeks as well as maintenance resulted from once per week of IHT.

Training time included both training periods completed in and outside the laboratory and was not different between HT_{MAX}, HT_{MIN}, and HT_{CON}. This indicates that the current findings were not because of changes in training volume. Additionally, VO_{2peak} and vVO_{2peak} did not change throughout the study, which is an important factor because of the fact that fitness level can affect HA adaptations.[21,23] Training did not induce changes in VO_{2peak}, and this could be because participants in this study were endurance-trained athletes. Training status was maintained throughout the study, which is a critical point in an HA study, as Ravanelli et al[26] indicated that training status is more important than aerobic fitness level in HA adaptations. The results of this study were independent of changes in aerobic fitness level and also their normal training.[21]

One major limitation of our study is that other factors (ie, extracurricular exercise, sleep, and nutrition) aside from IHT could have caused a change in a participant's time-trial performance.[9] However, to minimize the effects of alternative factors, participants were instructed to avoid strenuous exercise the day before trials and to practice similar nutritional habits for a period of 3 days before trials. Even though there were no differences in training volume, both in and outside the laboratory, throughout the study, training outside the laboratory was not controlled. This could have resulted in participants' training at different modalities. Also, trained athletes are known to adapt to the heat rapidly and hold the characteristics of heat-acclimated individuals; therefore, these findings may not be extrapolated to non–endurance trained individuals.[22,29] Last, female athletes were not included because of the impacts of menstrual cycle on internal body temperature.

CONCLUSION

Time trial after HA was significantly faster compared with when participants completed HAz alone, as well as when they were unacclimatized. Therefore, these results indicate that HA after HAz induced additional improvement in time-trial performance. IHT twice per week shows improvement in time-trial performance after 8 weeks, while IHT once per week maintains adaptations for 8 weeks. Furthermore, no IHT results in a loss of adaptations in time-trial performance after 4 weeks and even greater losses after 8 weeks. Thus, endurance-trained athletes looking to achieve peak performance may use IHT twice per week to improve and once per week to maintain time-trial performance after HAz and HA induction. Because of added physiological and psychological stress, HA induction should be performed with caution, especially right before competition since multiple heat exposures are required in a short period of time. However, using IHT can minimize this extraneous stress, while achieving positive adaptations for competition. Thus, this method can contribute to improvements in readiness for exercising in the heat without excessive stress.

AUTHORS

Yasuki Sekiguchi, PhD (Korey Stringer Institute, Department of Kinesiology, University of Connecticut, Storrs, Connecticut; and Department of Kinesiology and Sport Management, Texas Tech University, Lubbock, Texas); **Courteney L. Benjamin, PhD** (Korey Stringer Institute, Department of Kinesiology, University of Connecticut, Storrs, Connecticut; and Department of Kinesiology, Samford University, Birmingham, Alabama); **Ciara N. Manning, MS** (Korey Stringer Institute, Department of Kinesiology, University of Connecticut, Storrs, Connecticut); **Jeb F. Struder, MS** (Korey Stringer Institute, Department of Kinesiology, University of Connecticut, Storrs, Connecticut); **Lawrence E. Armstrong, PhD** (Human Performance Laboratory, Department of Kinesiology, University of Connecticut, Storrs, Connecticut); **Elaine C. Lee, PhD** (Human Performance Laboratory, Department of Kinesiology, University of Connecticut, Storrs, Connecticut); **Robert A. Huggins, PhD** (Korey Stringer Institute, Department of Kinesiology, University of Connecticut, Storrs, Connecticut); **Rebecca L. Stearns, PhD** (Korey Stringer Institute, Department of Kinesiology, University of Connecticut, Storrs, Connecticut); **Lindsay J. Distefano, PhD** (Human Performance Laboratory, Department of Kinesiology, University of Connecticut, Storrs, Connecticut); and **Douglas J. Casa, PhD** (Korey Stringer Institute, Department of Kinesiology, University of Connecticut, Storrs, Connecticut).

ORCID ID

Robert A. Huggins https://orcid.org/0000-0003-2174-8088

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