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Original research

The efficacy of weekly and bi-weekly heat training to maintain the physiological benefits of heat acclimation

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ABSTRACT

Objectives: To examine the efficacy of weekly and bi-weekly heat training to maintain heat acclimatization (HAz) and heat acclimation (HA) for 8 weeks in aerobically trained athletes.
Design: Randomized, between-group.
Methods: Twenty-four males (mean [m ± standard deviation [sd]; (age, 34 ± 12 y; body mass, 72.6 ± 8.8 kg, VO_{2peak}, 57.7 ± 6.8 $mL\cdot kg^{-1}\cdot min^{-1}$) completed five trials (baseline, following HAz, following HA (HAz + HA), four weeks into heat training [HT_{WK4}], and eight weeks into HT [HT_{WK8}] that involved 60 min of steady-state exercise (59.1 ± 1.8% vVO_{2peak}) in an environmental laboratory (wet bulb globe temperature [WBGT], 29.6 ± 1.4 °C) on a motorized treadmill. Throughout exercise, heart rate (HR) and rectal temperature (T_{rec}) were recorded. Following HAz + HA, participants were assigned to three groups: control group (HT_0), once per week heat training (HT_1), and twice per week heat training (HT_2). HT involved heated exercise (WBGT, 33.3 ± 1.3 °C) to achieve hyperthermia (38.5–39.75 °C) for 60 min. Repeated measures ANOVAs were used to determine differences.
Results: HAz + HA resulted in significant improvements in HR ($p < 0.001$) and T_{rec} ($p < 0.001$). At HT_{WK8}, HR was significantly higher in HT_0 (174 ± 22 $beats\cdot min^{-1}$) compared to HT_2 (151 ± 17 $beats\cdot min^{-1}$, $p < 0.023$), but was not different than HT_1 (159 ± 17 $beats\cdot min^{-1}$, $p = 0.112$). There was no difference in % change of T_{rec} from post-HAz + HA to HT_{WK4} (0.6 ± 1.3%; $p = 0.218$), however, HT_{WK8} (1.8 ± 1.4%) was significantly greater than post-HAz + HA in HT_0 ($p = 0.009$).
Conclusions: Bi-weekly HT provided clear evidence for the ability to maintain physiological adaptions for 8 weeks following HA.

Practical implications

- Bi-weekly heat training maintained cardiovascular, rectal temperature, skin temperature, and sweat adaptations in aerobically training individuals for 8 weeks following heat acclimation.
- Weekly heat training may be enough to maintain adaptations for 8 weeks following heat acclimation in some aerobically training individuals.
- Aerobically training athletes interested in using heat acclimation primarily to lower T_{rec} may be able to complete heat acclimation up to four weeks prior to a competition in the heat, as this variable did not show signs of decay in this population.

1. Introduction

Major sporting events, such as the 2020 Tokyo Olympics and the 2022 FIFA World Cup in Qatar have been and are of concern for elite athletes and spectators due to the extreme environmental conditions of these venues.[1] Heat acclimation (HA), the process of systematic heat exposures in an artificial environment to develop improved cardiovascular and thermoregulatory benefits, has been deemed an effective heat mitigation strategy.[2] Heat acclimatization (HAz) refers to a similar process, although this type of training occurs in a natural environment. While research has demonstrated that HA is an impactful strategy to optimize performance and safety when competing in the heat, strategies to sustain HA benefits throughout a competitive season are not well understood[3,4].

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There is evidence demonstrating the effectiveness of HA in team sports as well as individual sports and activities.[5–8] However, the environmental conditions that athletes may compete in can greatly fluctuate due to the timing of the sport season or the travel involved with a given sport.[9,10] Several studies have demonstrated that the adaptions in biomarkers of HA (rectal temperature [T_{rec}], heart rate [HR], sweat rate [SR]) decay without sustaining heat exposure.[3,11,12] A recent meta-analysis by Daanan et al. demonstrated that T_{rec} and HR responses that were improved by HA reduced ~2.5% per day without continued heat exposure.[13] While the evidence for HA decay is strong, the increased sweating and skin blow flow,[14] improved evaporative cooling,[15] greater cardiac stability,[16] improved fluid dynamics,[17] earlier onset of sweating,[18,19] and greater sweat sensitivity[20] of aerobically trained individuals could result in a slower rate of decay than untrained individuals.[5] This potentially slower rate of decay creates a potential opportunity for reduced heat training frequency following initial HA when preparing for competition in the heat since.

Although the time course of the gain and decay of the many benefits of HA are well-established, limited research has investigated the effectiveness of intermittent exercise-heat exposures, or heat training (HT), to sustain the adaptions over an extended period of time.[21] To our knowledge, only one study has investigated the implementation of an exercising heat exposure once every five days for four weeks following HA.[21] With this protocol, physiological adaptations did not deteriorate to the same magnitude as the control group, however, some decay was still observed with HT.[21] Therefore, the optimal frequency of HT following HA is currently unknown. Throughout the course of many major sport seasons, the environmental conditions transition from hot to temperate and then cold, as observed in American fall sports. In competitive sports where international travel is required, athletes are often not prepared for the environment of their competition. To address the need for balancing sport-specific training, strength training, and recovery prior to a major competition, an effective HT strategy is needed to maintain the benefits of HA that will assist athletes in performing optimally in the heat.[22,23] Therefore, the purpose of this study was to examine the efficacy of weekly and bi-weekly HT for four and eight weeks following HA. We hypothesized that bi-weekly HT will result in less decay than weekly HT and that both HT protocols will result in less decay than no heat training.

2. Methods

Twenty-four male endurance athletes (mean[m] ± standard deviation [sd]; age, 34 ± 12 years; height, 178.44 ± 6.31 cm; body mass, 72.56 ± 8.81 kg; VO_{2peak} 57.7 ± 6.8 $mL \cdot kg^{-1} \cdot min^{-1}$) provided written informed consent to participate in this study, which was approved by the <remove for review> Institutional Review Board.

In a randomized, between-group study design, participants completed five trials that involved 60 min of steady state exercise (59.1 ± 1.7% baseline vVO_{2peak}) in an artificial environmental laboratory (m ± sd; ambient temperature [T_{amb}], 35.4 ± 1.1 °C; relative humidity [%RH], 46 ± 2%; Wet Bulb Globe Temperature [WBGT] 29.6 ± 1.4 °C; wind speed, 1.8 ± 0.1 $m \cdot sec^{-1}$) on a motorized treadmill (T150; COSMED, Traunstein, Germany). These trials served to test the efficacy of the various heat training protocols. This study was part of a larger study design that lasted approximately 6 months (Fig. 1). The first trial was performed in an unacclimatized physiological state (May–June in New England, USA). The second trial was performed following HAz that involved self-directed summer training (August–September in New England, USA). The third trial occurred following five days of HA (HAz + HA), which involved exercise to achieve hyperthermia (T_{rec}, 38.50–39.75 °C) for 60 min in the heat (m ± sd; T_{amb}, 39.1 ± 1.4 °C; %RH, 51.0 ± 8.4%; WBGT 33.2 ± 2.0 °C; wind speed, 0 ± 0 mph). Specifically, the participants began exercise at 70% vVO_{2max} on a treadmill to increase T_{rec}. Following this initial bout, the exercise intensity was moderated throughout the remainder of the session to achieve the desired T_{rec} range. Detailed information on this portion of the study, including the protocol and results are reported elsewhere.[24]

Following HAz + HA, participants were randomly assigned to three HT groups: 1) control group (HT_0) that received no additional heat training following HA ($n = 8$), 2) a group that completed weekly HT for eight weeks (HT_1) ($n = 9$), and 3) a group that completed bi-weekly HT for eight weeks (HT_2) ($n = 10$). All participants completed the same steady-state trial used at baseline, post-HAz, and post-HAz + HA approximately four weeks following HA (HT_{WK4}) and eight weeks following HA (HT_{WK8}). Participants continued their normal training outside of the lab during this period. HT involved the same protocol that was utilized for HA. Specifically, participants exercised on a motorized treadmill in the heat to achieve hyperthermia (T_{rec}, 38.50–39.75 °C) for 60 min in the

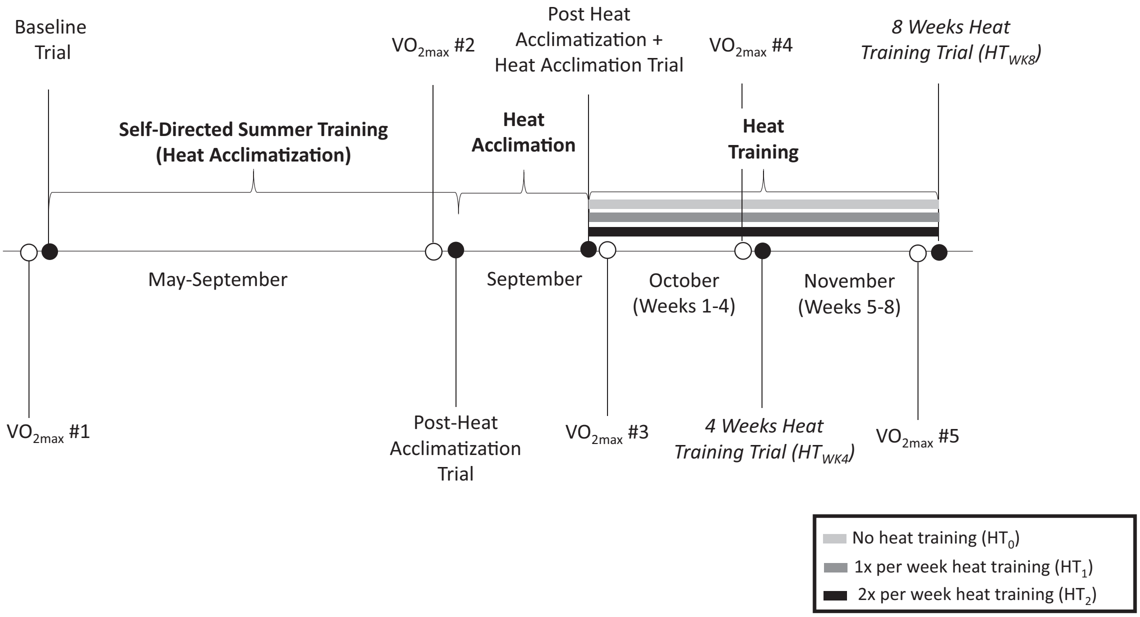


Fig. 1. Study timeline.

heat (T_{amb}, 39.8 ± 0.8 °C; %RH, 48.7 ± 6.8%; WBGT, 33.3 ± 1.3 °C). The sixty-minute clock did not start until the participant reached 38.50 °C so the average total session time was also recorded (83 ± 5 min).

In each of the five trials, HR and T_{rec} were recorded every 5 min. HR was measured with a chest strap (H10®, Polar Electro™, Kempele, Finland) and participants were instructed to insert a rectal probe 10 cm passed the anal sphincter for internal body temperature assessment (MP160; BIOPAC Systems Inc., Goleta, CA, USA). Ending HR and Trec were utilized for analysis. A weighted mean skin temperature (T_{sk}) was calculated, according to Ramanathan, by continuously collecting measurements from the thigh, calf, chest, and upper arm throughout the test (iButton; iButton Link LLC., Whitewater, WI, USA).[25] SR was assessed by taking a nude body mass measurement prior to and immediately post exercise, following towel drying. In the event participants needed to urinate during the trial, urine was collected and the weight was considered in the sweat rate calculation. Sweat electrolyte concentrations (sodium [Na+], potassium [K+], and chloride [Cl-]) were also assessed via the whole-body wash-down technique.[26] Euhydration was ensured prior to each trial with the examination of urine specific gravity (USG) and urine color and no fluid was provided during the trial.[27] Euhydrated was defined as a USG less than or equal to 1.020. In the event a participant arrived with a USG >1.020 and <1.025, the participant consumed 500 mL of fluid prior to starting the trial. If the USG was >1.025, the trial was rescheduled for a different time.

To account for potential changes in aerobic fitness surrounding this protocol VO_{2peak} was assessed five times: 1) before the first trial ($VO_{2peak}^{\#1}$, 2) post-HAz ($VO_{2peak}^{\#2}$), 3) post-HA ($VO_{2peak}^{\#3}$), 4) 4 weeks into HT ($VO_{2peak}^{\#4}$), 5) 8 weeks into HT ($VO_{2peak}^{\#5}$). To assess VO_{2peak}, participants completed a graded exercise test that involved increasing the speed of the treadmill by 0.8–1.6 kph every 2 min until volitional exhaustion. Additionally, participant's training outside of the lab was captured using their own wearable devices (Garmin, $n = 21$ [Forerunner® Fenix® Vivoactive® Garmin™ Ltd., Olathe, Kansas, USA]; Polar H10 and Polar Beat application, $n = 3$ [H10®, Polar Electro™, Kempele, Finland]).[28] In addition to these devices, 3 participants also utilized cycling computers to track their cycling training (Wahoo ELEMNT Bolt, $n = 1$ [ELEMNT Bolt, Wahoo Fitness®, Atlanta, GA, USA], Garmin Edge, n = 1 [Edge®, Garmin Ltd., Olathe, Kansas, USA], Bryton Rider 15, n = 1 [Rider 15®, Bryton™ Inc., Taipei City, Taiwan]) (Supplementary Table 1). Meteorological data from training sessions that were performed outside were extracted from the nearest available automated surface observing station (ASOS). The location of training was determined by the GPS device and the latitude/longitude of that training session location was utilized to determine the closest weather station. Daytime WBGTs (7 a.m.–7 p.m.) were modeled using a Heat Stress Advisor software package (version 2005; Zunis Foundation, Tulsa, OK; Coyle 2000),[29] which is designed to work with weather station data; nighttime WBGTs were computed using the Liljegren model with solar radiation set to zero.[30] The majority of training of training sessions from post-HAz + HA until HT_{WK4} (78%) and from HTWK4 to HTWK8 (76%) were outdoor running.

Following random assignment, a repeated measures ANOVA was utilized to ensure that there were no differences in participant characteristics (VO_{2peak}, body mass, and age) between the groups. Two participants were unable to complete the trial at baseline ($n = 1$, HT_1; n = 1 HT_2) and one participant was unable to complete the HT_{WK4} trial (HT_0). Baseline trial data were replaced with post-HAz data, since these values were considered baseline values in this study design. HT_{WK4} data were replaced with the average of the post-HAz + HA trial and the HT_{WK8} trial. All data were checked for normality with the Shapiro-Wilk test and in the presence of a significant Mauchly's Test of Sphericity, Greenhouse-Geisser correction was used. Repeated measures ANOVA were utilized to analyze differences between groups. Pairwise differences between groups and within groups at various time points were assessed post-hoc using paired (within group) and independent (between groups) *t*-tests. Cohen's d (within group) and Hedge's g (between group) effect sizes (ES) were calculated to quantify the magnitude of pairwise differences. Hedge's g effect sizes were used to account for different sample sizes between groups. Statistical significance was set at $p < 0.05$, a priori. Data are reported as m ± sd. All statistical analyses were completed using SPSS Statistics for Mac (version 25, IBM Corp., Armonk N.Y., USA).

3. Results

The days between HT sessions for HT_1 and HT_2 were recorded (HT_1, 7 ± 2 days; HT_2, 4 ± 2 days). The days between the most recent HT session and HT_{WK4} and HT_{WK8} were recorded for HT_1 and HT_2 (HT_1 HT_{WK4}, 7 ± 2 days; HT_2 HT_{WK4}, 3 ± 1 days; HT_1 HT_{WK8}, 8 ± 4 days; HA_{MAX} HT_{WK8}, 3 ± 1 days). Additionally, the days between the post-HAz + HA trial and HT_{WK4} and HT_{WK8} were recorded for HT_0 (post-HAz + HA and HT_{WK4}, 29 ± 2 days; HT_{WK4} and HT_{WK8}, 25 ± 4 days). Participants arrived euhydrated for each trial (USG, 1.010 ± 0.009; urine color, 1 ± 1).

There were no changes in VO_{2peak} at any time point throughout this protocol ($p > 0.05$). There were no differences between the HT_0, HT_1,

Table 1

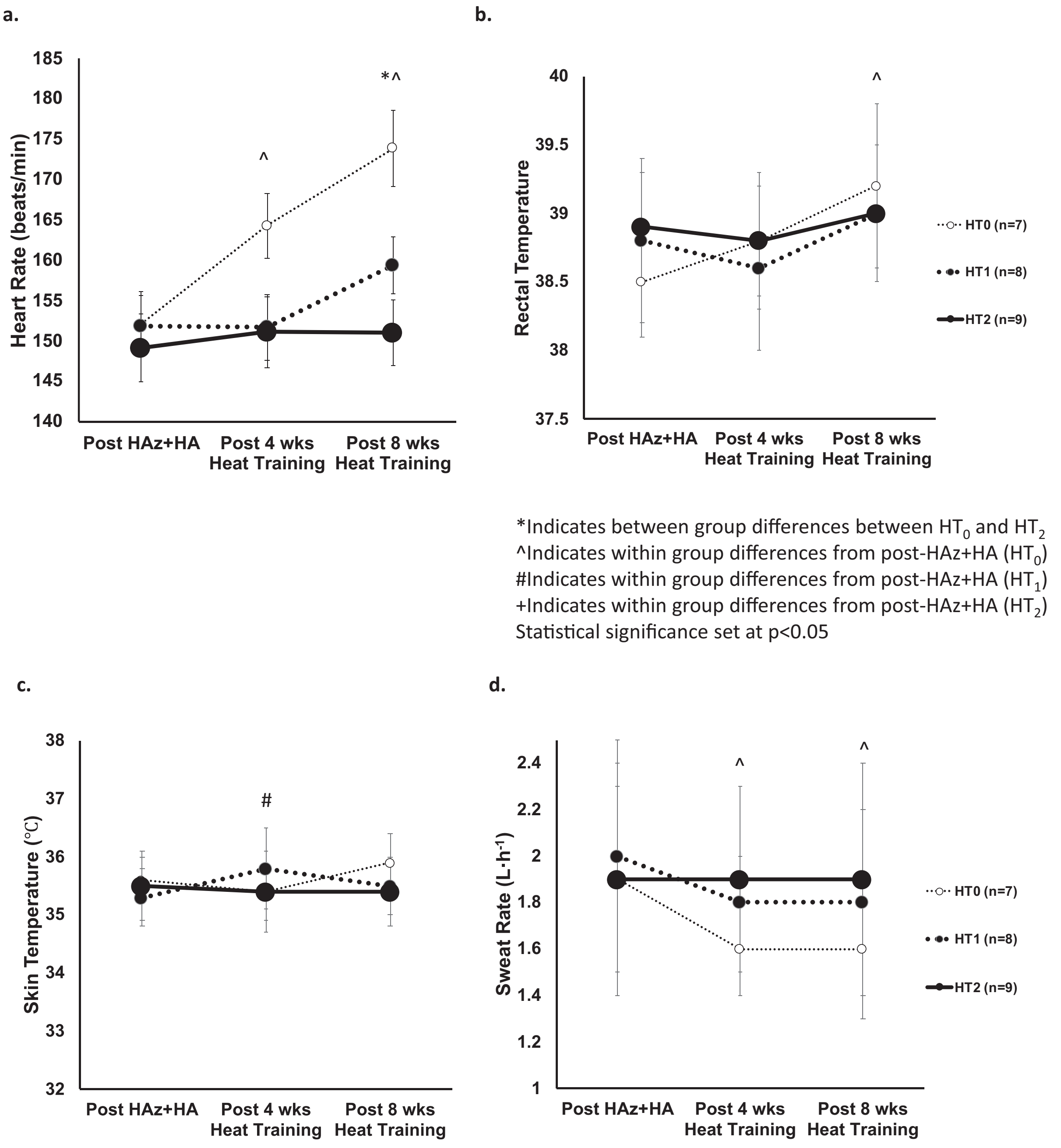
Group comparisons of physiological outcomes of no heat training (HT_0), once per week heat training (HT_1), and twice per week heat training (HT_2) following heat acclimatization plus heat acclimation (post-HAz + HA) after four weeks (HT_{WK4}) and eight weeks (HT_{WK8}).

	HT_0			HT_1			HT_2		
	Post-HAz + HA	HT_{WK4}	HT_{WK8}	Post-HAz + HA	HT_{WK4}	HT_{WK8}	Post-HAz + HA	HT_{WK4}	HT_{WK8}
HR (bpm)	152 ± 16	$164 \pm 16^{\wedge}$	$174 \pm 22^{\wedge}$	152 ± 14	152 ± 17	159 ± 13	149 ± 17	151 ± 19	$151 \pm 17^{*}$
T_{rec} (°C)	38.5 ± 0.4	38.8 ± 0.4	$39.2 \pm 0.6^{\wedge}$	38.8 ± 0.6	38.6 ± 0.6	39.0 ± 0.5	38.9 ± 0.4	38.8 ± 0.5	39.0 ± 0.5
T_{ski} (°C)	35.6 ± 0.4	35.4 ± 0.5	35.9 ± 0.5	35.3 ± 0.5	$35.8 \pm 0.7^{\wedge}$	35.5 ± 0.5	35.5 ± 0.6	35.4 ± 0.7	35.4 ± 0.6
SR ($L \cdot h^{-1}$)	1.9 ± 0.4	$1.6 \pm 0.2^{\wedge}$	$1.6 \pm 0.3^{\wedge}$	2.0 ± 0.5	1.8 ± 0.2	1.8 ± 0.4	1.9 ± 0.5	1.9 ± 0.4	1.9 ± 0.5
[Na+] ($mEq \cdot L^{-1}$)	832.5 ± 257.2	$1286.8 \pm 439.9^{\wedge}$	$1309.6 \pm 399.5^{\wedge}$	766.3 ± 225.3	$1024.5 \pm 254.8^{\wedge}$	$1309.8 \pm 286.9^{\wedge}$	789.5 ± 201.2	$964.3 \pm 251.2^{\wedge}$	901.3 ± 310.3
[Cl-] ($mEq \cdot L^{-1}$)	1244.0 ± 473.0	1865.8 ± 560.2	1857.2 ± 577.9	1125.9 ± 300.7	1541.9 ± 345.7	1459.8 ± 410.9	1198.8 ± 319.2	1487.9 ± 309.2	1307.5 ± 483.4
[K+] ($mEq \cdot L^{-1}$)	202.2 ± 47.2	212.5 ± 35.9	223.7 ± 26.4	190.8 ± 29.6	190.5 ± 28.1	189.4 ± 28.1	207.1 ± 63.5	207.4 ± 51.0	184.6 ± 52.8

HR: heart rate.
T_{rec}: rectal temperature.
T_{ski}: skin temperature.
SR: sweat rate.
[Na+]: sweat sodium concentration.
[Cl-]: sweat chloride concentration.
[K+]: Sweat potassium concentration.
* Indicates statistically significant differences from HT_0, $p < 0.05$.
$^{\wedge}$ Indicates statistically significant differences from post-HAz + HA, $p < 0.05$.

and HT_2 in VO_{2peak} (HT_0 58.6 ± 4.7 $mL \cdot kg^{-1} \cdot min^{-1}$; HT_1 58.1 ± 9.7 $mL \cdot kg^{-1} \cdot min^{-1}$; HT_2 56.5 ± 5.6 $mL \cdot kg^{-1} \cdot min^{-1}$; $p = 0.800$), age (HT_0 33 ± 8 yrs.; HT_1 34 ± 13 yrs.; HT_2 37 ± 14 yrs.; $p = 0.706$), and body mass (HT_0 72.0 ± 9.8 kg; HT_1 72.4 ± 7.2 kg; HT_2 73.2 ± 10.1 kg; $p = 0.961$) following HA. Between baseline and post-HAz + HA, significant mean differences were observed for ending exercise HR ($p < 0.001$) and ending exercise T_{rec} ($p < 0.001$), confirming successful HA. Additional data supporting this statement is available elsewhere.[24] The outside training environmental conditions from post-HAz + HA to HT_{WK4} (WBGT, 15.9 ± 5.3 °C) and from HT_{WK4} to HT_{WK8} (WBGT, 9.7 ± 5.9 °C) were recorded.

There was a significant interaction for HR between groups ($p = 0.018$) (Table 1). At HT_{WK8}, HR was significantly greater in HT_0 compared to HT_2 ($p = 0.023$; ES = 1.19), but was not different than HT_1 ($p = 0.112$; ES = 0.82) (Fig. 2a). There was a significant interaction for HR within groups ($p < 0.001$). HT_0 had a significantly



*Indicates between group differences between HT_0 and HT_2
^Indicates within group differences from post-HAz+HA (HT_0)
#Indicates within group differences from post-HAz+HA (HT_1)
+Indicates within group differences from post-HAz+HA (HT_2)
Statistical significance set at p<0.05

*Indicates between group differences between HT_0 and HT_2
^Indicates within group differences from post-HAz+HA (HT_0)
#Indicates within group differences from post-HAz+HA (HT_1)
+Indicates within group differences from post-HAz+HA (HT_2)
Statistical significance set at p<0.05

Fig. 2. Change in heart rate (a), rectal temperature (b), skin temperature (c), and sweat rate (d) from post heat acclimatization plus heat acclimation (post HAz + HA) to four weeks following heat acclimatization plus heat acclimation (post 4 wks Heat Training) and eight weeks following heat acclimatization plus heat acclimation (post 8 wks Heat Training).

greater HR at HT_{WK4} ($p = 0.001$; ES = 0.76) and HT_{WK8} ($p = 0.003$; ES = 1.13) compared to post-HAz + HA, while HT_1 did not demonstrate differences between post-HAz + HA at HT_{WK4} ($p = 0.995$; ES = 0.01) and HT_{WK8} ($p = 0.084$; ES = 0.56). Similarly, HT_2 also did not differ from post-HAz + HA at HT_{WK4} ($p = 0.652$; ES = 0.11) or HT_{WK8} ($p = 0.523$; ES = 0.31).

While there was no significant interaction for between group difference in T_{rec} at post-HAz + HA, HT_{WK4}, and HT_{WK8} ($p = 0.05$), however, there was a significant interaction for the within group analysis ($p < 0.001$) (Table 1). HT_0 demonstrated significantly higher ending T_{rec} at HT_{WK8} compared to post-HAz + HA ($p = 0.009$; ES = 1.40) (Fig. 2b). There were no within group differences in ending T_{rec} at HT_{WK4} ($p = 0.540$; ES = 0.22) or at HT_{WK8} ($p = 0.320$; ES = 0.36) in the HT_1 group. Similarly, there were no within group differences in ending T_{rec} at HT_{WK4} ($p = 0.430$; ES = 0.23) or at HT_{WK8} ($p = 0.370$; ES = 0.17) in the HT_2 group.

There was no significant interaction for SR between groups ($p = 0.143$) (Table 1). There was a significant interaction ($p = 0.033$) within groups. Specifically, in HT_0 post-HAz + HA had a significantly higher SR than HT_{WK4} ($p = 0.045$; ES = 0.95) and HT_{WK8} ($p = 0.024$; ES = 0.85) (Fig. 2d). In HT_1, HT_{WK4} and HT_{WK8} were not different than post-HAz + HA. There was no significant interaction ($p = 0.057$) for T_{sk} between groups ($p = 0.057$) (Table 1). There was a significant interaction within groups for T_{sk} ($p < 0.001$). HT_1 demonstrated significantly higher T_{sk} at HT_{WK4} compared to post-HAz + HA ($p = 0.018$; ES = 0.82) (Fig. 2d). No other differences were observed within groups.

There was not a significant interaction for the between group analysis for [Na+] ($p = 0.141$), [Cl-] ($p = 0.283$), or [K+] ($p = 0.558$) (Table 1). There was a significant interaction for the within group analysis of [Na+] ($p = 0.049$) but not [Cl-] ($p = 0.085$) or [K+] ($p = 0.126$) (Table 1). Within-group post-hoc analysis showed that [Na+] was significantly higher at HT_{WK4} compared to post-HAz + HA in HT_0 ($p = 0.003$; ES = 1.26) and at HT_{WK8} compared to post-HAz + HA ($p = 0.004$; ES = 1.42). [Na+] was significantly higher at HT_{WK4} compared to post-HAz + HA in HT_1 ($p = 0.013$; ES = 1.07) and at HT_{WK8} compared to post-HAz + HA ($p = 0.013$; ES = 2.11). [Na+] was significantly higher at HT_{WK4} compared to post-HAz + HA in HT_2 ($p = 0.010$; ES = 0.77), however, there was no difference between post-HAz + HA and HT_{WK8} ($p = 0.193$; ES = 0.43).

4. Discussion

Findings from this study point to the effectiveness of a twice weekly, and possibly a once weekly, HT program to maintain the physiological benefits of HA. Two specific factors most likely contributed to these results: 1) the training intensity and 2) the training status of the participants. First, the heat training used throughout this study involved high levels of hyperthermia (T_{rec}, 38.50–39.75 °C) for 60 min, which most likely resulted in greater physiological responses than the traditional isothermal approach that involves clamping T_{rec} at 38.50 °C. No other study to date has used this type of intensity to maintain HA. Second, the participants' high aerobic training volume likely influenced the findings of these HT programs, since it has been established that increased aerobic training volume results in thermoregulatory benefits.[31] Previous research has investigated the decay of physiological responses following HA. Daanen et al. examined the impacts of one method of HA that involved 9 consecutive days of moderate environmental stress followed by 3 days of severe environmental stress and determined that the optimal physiological responses were observed 3 and 7 days following HA.[32] These findings bring two distinctive points to light. First, similar to any fitness training program, individuals need time to recover and allow adaptations to optimize following a HA protocol for the full benefits to be observed. This is evident from previous research[22,23] and from the improvements observed in T_{rec} at HT_{WK4} in the present study in HT_1 and HT_2. The HT protocols for the four weeks following HA seemed to allow the participants to recover while continuing to maintain physiological benefits. Second, decay did not happen as rapidly as previously reported,[11] especially in a fit population that undergoes an effective HA protocol.

It appears that in this aerobically trained population, the HT_0 group observed physiological decay in HR (+23 beats·min^{-1}), SR (−0.3 L·h^{-1}), and sweat [Na+] (+454 mEq·L^{-1}) four weeks after HA. All other variables demonstrated nonsignificant changes at HT_{WK4} in HT_0. Interestingly, T_{rec} did not show significant changes in HT_0 four weeks following HAz + HA. Previous literature demonstrated that HR and T_{rec} decayed two weeks following short-term HA.[33] In the present study, T_{rec} not decaying four weeks after HAz + HA is most likely related to multiple components of the study design, including the thermal load of this protocol, the high aerobic fitness of these participants, and the moderate environmental conditions experienced during free-living training throughout this period (WBGT, 15.9 ± 5.3 °C).[13,33] Eight weeks following HA, HT_0 exhibited a mean of 22 beats·min^{-1} higher HR, a mean of 0.7 °C higher T_{rec}, a mean of 0.3 L·h^{-1} higher sweat rate and a mean of 1310 mEq·L^{-1} higher [Na+] compared to post-HAz + HA, providing clear evidence of decay. This was expected, as the environmental conditions experienced during free-living training in this phase were cool (WBGT, 9.7 ± 5.9 °C).

A previous study investigating the efficacy of HT in moderately aerobically fit individuals saw a slower rate of decay with a heat exposure once every five days compared to a control group.[21] New findings from this study indicate that decay in T_{rec} may be much slower than previously reported in an aerobically trained population, as evidenced by no change in Trec four weeks following HAz + HA in the control group. Additionally, weekly HT may be useful to maintain adaptations in this population.

Future investigations are needed to determine the mechanism underlying the variety of responses observed in HT_1. Although this distinction was needed to answer the current research question, one limitation of the current study design was the difference of protocols during testing and HT. A study using the same protocol for testing and HT might provide a detailed description of the changes that occur over the 4 wk. and 8 wk. periods following HA. Another limitation to this study is that there was some variability in days between sessions in the HT_2 group due to participant's schedules. Although very few participants were impacted, this variability could have influenced the results of this study. Finally, SR was estimated based on body mass changes and urine output. Other factors that could impact this measurement that were not accounted for in the present study include saliva, respiration, and metabolism.[34]

5. Conclusion

To summarize, twice weekly heat training provided clear evidence for the ability to maintain physiological adaptations following HA. Weekly heat training may be sufficient for some individuals to maintain the beneficial adaptations of HA, however, future research is needed to explore methods to individualize HT programs. Following unique HA and HT protocols, participants in this aerobically trained sample did not demonstrate signs of decay in all variables following 4 wk. without heat exposure. Not only are the present methods of HA and HT unique and effective, they are less time consuming than traditional HA and, therefore, may be more practical to implement.

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Declaration of interest statement

All of the authors included on this manuscript were employed by or on the advisory board of the Korey Stringer Institute at the time of data collection. The Korey Stringer Institute holds several corporate partner relationships, including the National Football League, Gatorade, Kestrel, Mission, CamelBak, National Athletic Training Association, and Defibtech.

Confirmation of ethical compliance

This research was approved by the Institutional Review Board at the University of Connecticut. All participants provided informed written consent prior to the start of this research study.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jsams.2021.10.006.

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