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Thermoregulatory Adaptations following Sprint Interval Training

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Abstract

Traditional endurance training typically involves weeks of long-duration (60–90 min) exercise performed at a moderate to vigorous intensity. An alternative paradigm, sprint interval training, is characterized by multiple bouts of short-duration, high-intensity exercise. Similar fitness benefits from the two paradigms have been demonstrated, but whether sprint interval training—like traditional endurance training—induces heat acclimation remains unclear.

Purpose

To test the hypothesis that sprint interval training performed over six sessions results in measureable thermoregulatory and cardiovascular adaptations consistent with heat acclimation.

Methods

Seven untrained men [mean $\pm$ SD, 13 $\pm$ 5% body fat, 22 $\pm$ 3 y, 3.1 $\pm$ 0.3 L/min peak oxygen uptake ($\dot{V}O_{2peak}$)] performed 6 sprint interval training sessions over 12 days with 48–72 h between sessions. Sessions consisted of 4–6 thirty-second Wingate Anaerobic Tests separated by ~4 min. Before and after the two-week training protocol, participants cycled for 30 min at 65% $\dot{V}O_{2peak}$ in 25 °C to assess the effects of sprint interval training on heat acclimation.

Results

Main outcome variables (onset of sweating, sweat sensitivity, heart rate at end of exercise, percent change in plasma volume, and core temperature change from pre- to post-exercise) were not different from pre- to post-training (all $p > 0.05$).

Conclusion

Two weeks of sprint interval training performed under the conditions specified does not result in heat acclimation.

Keywords: acclimatization, sweating, heat stress, thermoregulation, high-intensity exercise

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Introduction

Traditional endurance training typically involves long-duration (60–90 min), moderate- to vigorous-intensity exercise [60–80% maximal oxygen uptake ($\dot{V}O_{2max}$)], performed 3–5 days/week for 6–8 weeks (Coyle, 2005) to elicit improvements in cardiorespiratory fitness. An alternative to long-duration endurance exercise to induce improvements in cardiorespiratory fitness is sprint interval training (SIT), characterized by short-duration exercise sessions (~4–20 min total time per session) consisting of 4–7 bouts of 30-s "all-out" exercise coupled with rest bouts of 3–5 min. Typical regimens consist of spreading 6–14 sessions over 2 weeks (Burgomaster, Hughes, Heigenhauser, Bradwell, & Gibala, 2005; Rodas, Ventura, Cadefau, Cusso, & Parra, 2000). Compared with traditional endurance training, SIT represents a time-efficient training paradigm with comparable cardiorespiratory fitness benefits (Burgomaster et al., 2005; Gibala et al., 2006; Rodas et al., 2000).

In addition to fitness benefits, traditional endurance training can induce heat acclimation, i.e., physiological adjustments that facilitate greater heat tolerance. Improved heat tolerance from endurance training is mediated by increased plasma volume and stroke volume and thereby improved cardiovascular stability during exercise in the heat (Avellini, Shapiro, Fortney, Wenger, & Pandolf, 1982; Senay & Kok 1977) as well as increased sweat rate (Gisolfi & Robinson, 1969; Henane, Flandrois, & Charbonnier, 1977), although this is not a consistent finding (Shvartz, Saar, Meyerstein, & Benor, 1973; Shvartz et al., 1977). Greater effects are observed if the training is performed in a hot environment (Roberts, Wenger, Stolwijk, & Nadel, 1977). Heat acclimation protocols have traditionally involved consecutive days of training in the heat for at least 60–90 min per day at a moderate intensity (~50% $\dot{V}O_{2max}$ or higher) for 6–10 days (Lorenzo, Halliwill, Sawka, & Minson, 2010; Racinais et al., 2015). Nonetheless, some sources have reported the effectiveness of shorter (either duration of exercise or number of days or both) protocols (Chalmers, Esterman, Eston, Bowering, & Norton, 2014; Charlot et al., 2017; Garrett, Creasy, Rehrer, Patterson, & Cotter, 2012; Garrett, Goosens, Rehrer, Patterson, & Cotter, 2009; Garrett et al., 2014; Houmard et al., 1990; Kelly, Gastin, Dwyer, Sostaric, & Snow, 2016; Petersen et al., 2010). Of these, only a couple of studies involved short-duration exercise (e.g., high-intensity interval training or SIT), with mixed results (Kelly et al., 2016; McGarr, Hartley, & Cheung, 2014). Kelly et al. (2016) investigated the effect of five sessions of high-intensity interval training (3 × 5 min bouts with intensity alternating between 30% and 90% $\dot{V}O_{2max}$ every 30 s) spread over nine days on heat acclimation adaptations in moderately fit Australian football players. Perceptual responses (perceived exertion and thermal comfort) improved, but other markers of heat acclimation (heart rate, core temperature, sweat rate) were unaffected. McGarr et al. (2014) had moderately fit participants perform 4–5 repeated Wingate Anaerobic Tests (WAnT) over eight sessions in two weeks. Heat stress tests were administered before and after the training (60 min cycling at 65% peak oxygen uptake in 35 °C, 40% rh). SIT improved $\dot{V}O_{2max}$ but did not result in heat acclimation based on final rectal temperature (T_{re}) or change from baseline, sweat loss, skin blood flow change from baseline, or final heart rate. Onset of local sweat rate and sweat sensitivity (slope of sweat rate vs. core or mean body temperature) were not assessed. Training sessions were performed in a temperate environment (22–25 °C).

Taken together, understanding of short-term, high-intensity interval training for inducing heat acclimation remains incomplete. The Kelly et al. (2016) study utilized submaximal exercise intensities (and, therefore, a lower internal heat stimulus compared to maximal intensity exercise) and only five days of heat exposure and the McGarr et al. (2014) study involved training sessions in a temperate environment that would not have caused elevations in skin temperature needed to optimize heat acclimation (Regan, Macfarlane, & Taylor, 1996). Additionally, the participants in both studies were characterized as "moderately fit." More trained individuals may heat acclimate more rapidly (Armstrong & Maresh, 1991), but, as a result of their elevated fitness, they also may already have some degree of heat acclimation (Armstrong et al., 2007). Recreational athletes, industrial workers, and newly enlisted soldiers may have lower fitness levels, and thereby, lower initial states of heat acclimation; therefore, they may respond more favorably to a short-term, maximal-intensity training paradigm in terms of heat acclimation adaptations, but this has not been tested. Accordingly, the purpose of this study was to address the following research questions: (1) Do untrained individuals performing SIT for six sessions over two weeks experience adaptations consistent with heat acclimation? (2) Does performing SIT in a hot environment result in greater heat acclimation adaptations than performing SIT in a temperate environment?

We hypothesized that in untrained individuals, SIT performed for six sessions over two weeks results in heat acclimation adaptations, and greater adaptations would occur from SIT performed in a hot environment.

Methods

Research Design

Initially, a mixed model design was used with the intent to compare acclimation adaptations over time (within-groups analysis; pre- vs. post-SIT regimen) and between groups [temperate (~24 °C) vs. hot environment (~40 °C)]. After testing four people in the hot environment and three people in the temperate environment, however, inspection of the primary outcomes (e.g., heart rate at end of exercise,

T_{re} at end of exercise, sweat sensitivity) did not reveal any trends for group differences. Therefore, data from all participants were combined and a repeated measures design was utilized to assess responses pre- and post-SIT. A post hoc power analysis (Park & Schutz, 1999) revealed seven participants were sufficient to detect a 0.55 SD effect size (Potvin & Schutz 2000) for heart rate changes. The study was powered based on heart rate changes because cardiovascular adaptations are often reported as complete within the first six or seven days of heat acclimation (Periard, Racinais, & Sawka, 2015), and since an important goal of heat acclimation is to alleviate cardiovascular strain during physical activity in the heat.

Participants

Participants were men (mean $\pm$ SD, age = 22 $\pm$ 3 y, height = 171.9 $\pm$ 4.6 cm, weight = 74.3 $\pm$ 13.0 kg, body fat from skinfolds = 13 $\pm$ 5%) without known cardiovascular, pulmonary, or metabolic disease; asymptomatic; and physically inactive based on American College of Sports Medicine guidelines (i.e., not participating in at least 30 min of moderate intensity physical activity on at least 3 days per week for at least 3 months) (Exercise preparticipation health screening, 2018). The university's Institutional Review Board approved the study, and participants provided written informed consent before participating.

Graded Exercise Test

Participants visited the laboratory ten times after having avoided alcohol, caffeine, or non-prescription drugs the day before and the day of testing. Upon arrival on the first visit, participants completed the consent form and health, 24-h diet, and activity histories. They reported to the laboratory after a 2-h fast, but well hydrated [based on urine specific gravity (USG) < 1.020 (Casa et al., 2000)].

Next, 2 mL of blood were drawn from a superficial forearm vein, and then skinfolds were measured at seven sites for estimation of percent body fat (Jackson & Pollock, 1978). Participants then sat on a cycle ergometer in ~23 °C (40–50% rh) while resting blood pressure was obtained via auscultation of the brachial artery. Then they completed a graded exercise test to measure peak oxygen uptake ($\dot{V}O_{2peak}$). $\dot{V}O_2$ was measured breath-by-breath using a metabolic measurement system (TrueOne 2400, ParvoMedics, Sandy, UT) and averaged every 30 s. After stopping, participants cycled for 5–10 min at a self-selected intensity to cool down while blood pressure was measured. Heart rate (HR) and $\dot{V}O_2$ were measured continuously and rating of perceived exertion was recorded during the final 30 s of each stage. The highest 30-s $\dot{V}O_2$ obtained was considered $\dot{V}O_{2peak}$. After test completion, participants were given fluid and instructions for the next visit.

Heat Acclimation Assessment

One to three days after the graded exercise test, participants returned to the laboratory. The two meals prior to arrival were standardized in order to normalize sodium intake. These meals consisted of a combination of the following: a bagel (300 mg Na^+, 8 g protein, 1 g fat, 30 g carbohydrate), fruit juice (20 mg Na^+, 2 g protein, 0 g fat, 33 g carbohydrate), and granola bar (75 mg Na^+, 1 g protein, 3 g fat, 17 g carbohydrate) for one meal and a peanut butter and jelly sandwich (384 mg Na^+, 11 g protein, 14 g fat, 42 g carbohydrate), potato chips (130 mg Na^+, 1 g protein, 8 g fat, 12 g carbohydrate), apple (two different kinds were used; 0 mg Na^+, 0 or 1 g protein, 0 g fat, 22 or 34 g carbohydrate), and an oatmeal cream pie (170 mg Na^+, 1 g protein, 7 g fat, 26 g carbohydrate) for the other meal. Upon arrival, participants completed a 24-h history to verify adherence to pre-test instructions and then provided a urine sample to confirm adequate hydration (USG < 1.020). Next, they measured body weight using a digital scale (BWB-800, Tanita, Arlington Heights, IL) while wearing shorts and a t-shirt. Then they inserted a rectal thermocouple (RET-1, Physitemp Instruments, Inc., Clifton, NJ) ~10 cm past the anal sphincter for measurement of T_{re} and put on a HR monitor strap (Polar Electro, Inc., Woodbury, NY). Thermocouples (Type T, Omega Engineering, Stamford, CT) were taped to the lateral calf, lateral thigh, lower back, lower abdomen, upper back, and chest for measurement of mean skin temperature ($\bar{T}_{sk}$; TC-1000 Thermocouple Meter, Sable Systems, Las Vegas, NV) from the weighted average of the six sites (Taylor, Johnson, Kosiba, & Kwan, 1989). Mean body temperature ($\bar{T}_b$) was calculated using Equation 1 (Parsons, 2003):

$$\bar{T}_b = 0.9 \times T_{re} + 0.1 \times \bar{T}_{sk} \quad (1)$$

Next, participants entered an environmental chamber set to 25 °C and mounted a cycle ergometer (Velotron Dynafit Pro, Racer Mate, Inc., Seattle, WA). A plastic capsule was attached to the skin for measurement of local sweat rate using capacitance hygrometry (Vaisala, Woburn, WA). After instrumentation, participants completed an exercise test consisting of 30 min of cycling at 65% $\dot{V}O_{2peak}$ to assess heat acclimation. These conditions have been shown to be adequate to manifest heat acclimation adaptations, should they be present (Roberts et al., 1977). Fan airflow was directed at participants at ~2–3 m/s. T_{re}, HR, and local sweat rate were measured continuously. After the submaximal exercise bout, participants performed one to two WAnTs (Bar-Or, 1987) as familiarization for the SIT regimen. Work load was set to 7.5% body mass. After each WAnT, participants recovered for 4 min (rest or light cycling at ~30 W) before performing a subsequent bout (Gibala et al., 2006). After familiarization, instrumentation was removed and participants weighed themselves in a dry t-shirt and shorts. Then they were given fluid and instructions for the next six visits (SIT trials). Three days after the final SIT bout, participants returned to the laboratory and repeated the procedures outlined above for visits one (graded exercise test) and two (heat acclimation assessment), including the blood draw but excluding the familiarization bout.

SIT Regimen

At least three days after the baseline heat acclimation assessment and familiarization trial, participants began the SIT program. SIT was performed on Monday, Wednesday, and Friday over two weeks. Individuals arrived at the laboratory well-hydrated (USG < 1.020) and at least 2 h post-prandial. Preliminary procedures were identical to the second visit (heat acclimation assessment). Participants then mounted a cycle ergometer in an environmental chamber set to either 40 °C or 24 °C. They warmed up at 20%–40% heart rate reserve for approximately 5 min and then performed repeated 30-s WAnTs separated by 4 min (rest or light cycling at 30 W). Progression occurred by increasing the number of repeat cycling bouts from 4 during sessions 1 and 2, to 5 during sessions 3 and 4, to 6 during sessions 5 and 6; this paradigm has been shown to result in improved muscle oxidative capacity and performance (Gibala et al., 2006). During all sessions, T_{re} and HR were measured continuously.

Data Collection

All trials for a given subject were conducted at the same time of day to avoid circadian variation in body temperature and HR. T_{re}, $\bar{T}_{sk}$, and local sweat rate data were acquired continuously at a sampling rate of 50 Hz using a data acquisition system (Biopac, Santa Barbara, CA). Data were averaged every 30 s for offline analysis.

Data Analysis

Metabolic rate (M) was calculated using Equation 2:

$$M = \frac{\left(\dot{V}O_2 \cdot \left[\frac{RER-0.7}{0.3} e_c + \frac{1-RER}{0.3} e_f\right]\right)}{60}, \qquad (2)$$

where $\dot{V}O_2$ is measured in L/min (STPD), RER is respiratory exchange ratio, e_c is the caloric equivalent per liter of oxygen for the oxidation of carbohydrates (21,130 J), and e_f is the caloric equivalent per liter of oxygen for the oxidation of fat (19,630 J) (Kenny & Jay, 2013). Rate of metabolic heat production ($M - W$) was calculated as the difference between M and external work rate (W) (Kenny & Jay, 2013). Whole-body sweat rate during heat acclimation assessments was calculated as the difference between pre- and post-exercise body mass adjusted for respiratory water loss (Mitchell, Nadel, & Stolwijk, 1972) and metabolic mass loss (Kenny & Jay, 2013). Prism 5 computer software (GraphPad Software, La Jolla, CA) with segmental regression (Cheuvront et al., 2009) analysis was used to determine slopes and $\bar{T}_b$ onset thresholds for local sweating. Obvious plateau data were excluded from the analysis. In the event of a biphasic sweating response consisting of an early and late phase with different slopes (Cheuvront et al., 2009; Kondo et al., 2001), only the early (initial) phase was analyzed. Differences between mean data for pre- and post-SIT heat acclimation tests were analyzed using paired samples t-tests. Plasma volume changes were estimated using the changes in hemoglobin and hematocrit from pre- to post-SIT and the equation by Dill and Costill (1974) and a one-sample t-test was used to determine if the change was statistically significant. Analyses were performed using SPSS v. 24 for Windows (IBM SPSS Statistics, Somers, NY), and all hypothesis tests used an alpha level of 0.05. Data are reported as means $\pm$ SD.

Results

Hydration status was not different between pre-SIT (body mass $= 74.7 \pm 12.5$ kg; USG $= 1.011 \pm 0.007$) and post-SIT heat acclimation assessments (body mass $= 74.2 \pm 12.5$ kg; USG $= 1.015 \pm 0.003$) ($p = 0.81$ and 0.24 for body mass and USG, respectively). Body mass decreased from pre- to post-exercise during heat acclimation tests both before and after SIT, but reductions were greater pre-SIT (pre-SIT $= -0.46 \pm 0.09$ kg; post-SIT $= -0.39 \pm 0.09$ kg; $p = 0.04$).

As intended, ambient temperature during pre-SIT (25.2 $\pm$ 0.6 °C) and post-SIT (25.1 $\pm$ 0.9 °C) heat acclimation tests was not different ($p = 0.53$). $\bar{T}_{sk}$ at the end of the heat acclimation tests also was not affected by the SIT protocol (Table 1). The average $\bar{T}_{sk}$ during heat acclimation tests was higher after SIT ($p = 0.04$), but the difference was small ($\sim$1.4%; Table 1). As shown in Table 1, $\dot{V}O_{2peak}$ was not affected by the SIT protocol. Matching the relative intensity during the pre- and post-SIT heat acclimation tests [$p = 0.16$; after Roberts et al. (1977)] resulted in absolute $\dot{V}O_2$ that was on average $\sim$6% lower during the post-SIT heat acclimation test relative to that pre-SIT, but values were not statistically different ($p = 0.32$), and this did not result in different power outputs ($p = 0.76$).

In terms of heat acclimation, SIT did not affect the increase in HR from baseline during the heat acclimation exercise tests (pre-SIT $= 48 \pm 19$ beats/min; post-SIT $= 46 \pm 22$ beats/min; $p = 0.68$). Likewise, HR at the end of the heat acclimation tests was not differentially affected by SIT (Figure 1). The difference would have been even more slight had it not been for one subject who experienced a considerably high HR (>1 SD above the mean) at the end of the heat acclimation test pre-SIT. Considering the intensity at which he exercised was moderate (66% $\dot{V}O_{2peak}$; 120 W), it is unclear why his HR (193 beats/min; 93% HR_{max}) drifted so near his HR_{max} (207 beats/min) during this submaximal bout.

Table 1
Mean ± SD group (temperate vs. hot) and combined aerobic fitness changes and heat acclimation responses during heat acclimation exercise tests before and after two weeks of sprint interval training (SIT), as well as core temperature changes elicited during each SIT bout; $n = 3$ for temperate and $n = 4$ for hot unless specified otherwise.

	Temperate (24 °C)		Hot (40 °C)		Combined	
	Pre-SIT	Post-SIT	Pre-SIT	Post-SIT	Pre-SIT	Post-SIT
$\dot{V}O_{2peak}$ (L/min)	3.4 ± 0.1	3.3 ± 0.4	2.8 ± 0.1	2.7 ± 0.2	3.1 ± 0.3	3.0 ± 0.4
$\dot{V}O_{2peak}$ (mL/kg/min)	47.5 ± 1.9	47.0 ± 4.8	37.8 ± 6.1	36.1 ± 7.3	42.0 ± 6.8	40.8 ± 8.3
$\%\dot{V}O_{2peak}$	65.4 ± 4.7	62.4 ± 3.7	66.8 ± 1.5	66.2 ± 4.2	66.2 ± 3.0	64.6 ± 4.2
$\dot{V}O_2$ (L/min)	2.2 ± 0.1	2.1 ± 0.3	1.9 ± 0.1	1.8 ± 0.0	2.0 ± 0.2	1.9 ± 0.2
Power output (W)	158.0 ± 3.0	158.0 ± 25.0	120.0 ± 4.0	118.0 ± 13.0	136.0 ± 21.0	135.0 ± 27.0
Metabolic heat production (W)	610.1 ± 40.9	567.0 ± 71.1	549.6 ± 39.1	501.9 ± 12.5	575.6 ± 48.7	529.8 ± 54.5[a]
Metabolic heat production (W/kg)	8.4 ± 0.4	7.9 ± 0.9	7.4 ± 1.1	6.7 ± 1.2	7.8 ± 1.0	7.2 ± 1.2[a]
Whole-body sweat rate (L/h)	0.8 ± 0.3	0.5 ± 0.2	0.8 ± 0.1	0.7 ± 0.1	0.8 ± 0.2	0.6 ± 0.2
Final T_{re} (°C) ($n = 3$ for hot group and $n = 6$ for combined)	37.3 ± 0.5	37.6 ± 0.6	37.9 ± 0.3	37.8 ± 0.4	37.6 ± 0.5	37.7 ± 0.5
Final $\bar{T}_b$ (°C) ($n = 3$ for hot group and $n = 6$ for combined)	36.8 ± 0.4	37.1 ± 0.5	37.5 ± 0.3	37.4 ± 0.3	37.1 ± 0.5	37.2 ± 0.4
Final $\bar{T}_{sk}$ (°C)	32.3 ± 0.6	32.6 ± 1.3	32.6 ± 2.0	33.1 ± 1.6	32.5 ± 1.5	32.9 ± 1.4
Average $\bar{T}_{sk}$ (°C)	31.9 ± 0.7	32.6 ± 0.9	32.7 ± 1.4	32.9 ± 1.3	32.3 ± 1.2	32.8 ± 1.1[a]
ΔT_{re} WAnT 1 (°C)	0.4 ± 0.1		0.6 ± 0.2		0.5 ± 0.2	
ΔT_{re} WAnT 2 (°C)	0.6 ± 0.0		0.6 ± 0.2		0.6 ± 0.2	
ΔT_{re} WAnT 3 (°C) ($n = 3$ for hot group and $n = 6$ for combined)	0.6 ± 0.2		1.0 ± 0.2		0.8 ± 0.3	
ΔT_{re} WAnT 4 (°C)	0.5 ± 0.2		0.6 ± 0.1		0.6 ± 0.2	
ΔT_{re} WAnT 5 (°C)	0.5 ± 0.2		0.6 ± 0.1		0.6 ± 0.2	
ΔT_{re} WAnT 6 (°C)	0.7 ± 0.3		0.9 ± 0.1		0.8 ± 0.2	

Note. $\dot{V}O_2$ = oxygen uptake elicited during heat acclimation exercise tests; $\dot{V}O_{2peak}$ = peak oxygen uptake; $\%\dot{V}O_{2peak}$ = percent of peak oxygen uptake elicited during heat acclimation exercise tests; T_{re} = rectal temperature; $\bar{T}_b$ = mean body temperature; $\bar{T}_{sk}$ = mean skin temperature. ΔT_{re} WAnT 1–6 = change in T_{re} from baseline to end of Wingate Anaerobic Tests (WAnT) for each SIT session. Technical difficulties measuring rectal temperature were encountered in one subject in the hot group so data for T_{re} and $\bar{T}_b$ are based on $n = 3$ for hot group and $n = 6$ for combined data. Data are presented to demonstrate the similarities for outcomes between groups and were not analyzed statistically since data from both groups were combined for analysis. See Methods for more details.

[a]$p < 0.05$ vs. pre-SIT.

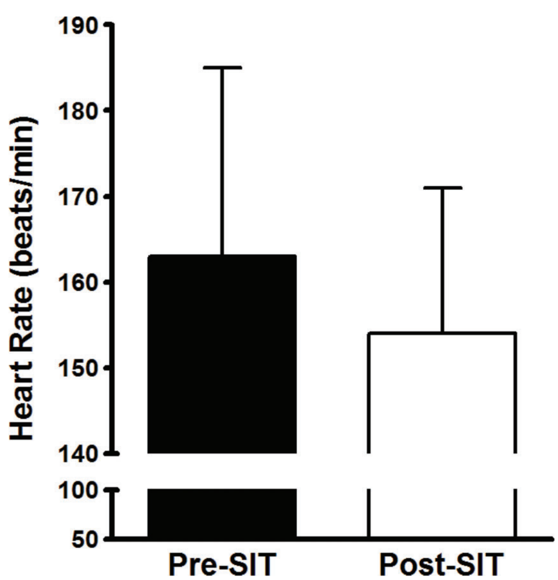

Figure 1. Mean ± SD heart rate at the end of 30 min of cycling at 65% peak oxygen uptake before and after two weeks of sprint interval training (SIT). The training protocol did not affect final heart rate during the submaximal exercise session ($p = 0.06$).

Technical difficulties measuring T_{re} were encountered in one subject, so T_{re} data (and other data derived from T_{re}—$\bar{T}_b$ and $\bar{T}_b$:sweat rate relation) are based on $n = 6$. As shown in Table 1, T_{re} increased ~0.5–0.8 °C during the SIT bouts, but exposure to elevated core body temperatures was brief (total duration of SIT bouts, including exercise and rest intervals, was only ~20 min, and temperatures increased and decreased corresponding to the work and rest intervals, respectively). The change in T_{re} from baseline to the end of exercise during the pre- and post-SIT heat acclimation tests was not affected by the training protocol (change in T_{re} pre-SIT heat acclimation assessment: 0.6 ± 0.1 °C; post-SIT heat acclimation assessment: 0.7 ± 0.1 °C; $p = 0.92$), nor was the final T_{re} or final $\bar{T}_b$ (Table 1). The $\bar{T}_b$ at which sweating began was not different after training compared to before (pre-SIT: 36.5 ± 0.6 °C; post-SIT: 36.6 ± 0.5 °C; $p = 0.43$). Likewise, training did not increase the local sweat rate per 1 °C rise in $\bar{T}_b$ (i.e., sweat sensitivity, or slope) ($p = 0.50$; Figure 2). The lack of changes in local sweat rate was reflected in the lack of differences in whole-body sweat rate from pre- to post-SIT (Table 1; $p = 0.06$). Lastly, the small increase in plasma volume from

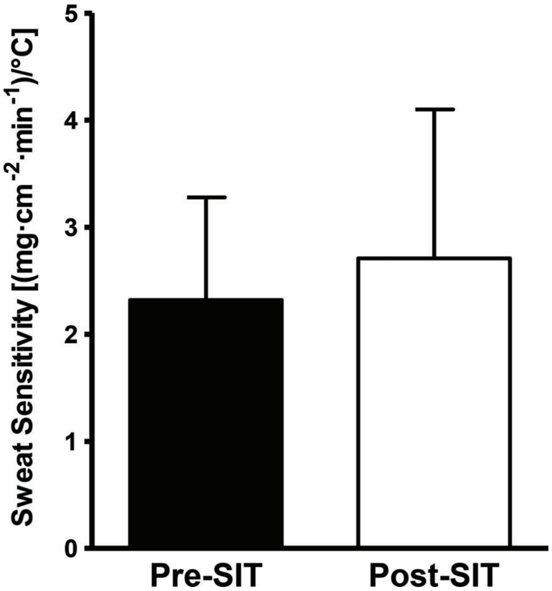

Figure 2. Mean $\pm$ SD sweat sensitivity, defined as the increase in local sweat rate per 1 °C increase in $\bar{T}_b$, before and after two weeks of sprint interval training (SIT). The training protocol did not affect the slope of this relationship ($p = 0.50$).

pre- to post-SIT was not considered statistically significant ($3.0 \pm 4.4\%$; $p = 0.13$).

Discussion

The primary finding of this study was that six sessions of SIT performed by untrained individuals did not result in heat acclimation adaptations as characterized using changes in HR from baseline, change in T_{re}, whole-body sweat rate, or sweat sensitivity assessed during a submaximal heat acclimation exercise test. Another main finding was that the SIT protocol used in this study did not improve $\dot{V}O_{2peak}$.

Some studies investigating SIT (McGarr et al., 2014; Trilk, Singhal, Bigelman, & Cureton, 2011) or short-term high-intensity training sessions (Rodas et al., 2000) have found improvements in cardiorespiratory fitness while others (Burgomaster, Hughes, Heigenhauser, Bradwell, & Gibalam, 2005), like our study, have not. The reason for the discrepant findings is uncertain but is likely related to differences in the exercise protocol used and the participants tested. Participants in the Burgomaster et al. (2005) and McGarr et al. (2014) studies were “recreationally active,” exercising 2–3 times per week (e.g., jogging, cycling, aerobics), yet $\dot{V}O_{2peak}$ increased after SIT in the latter but not the former of these two investigations. Participants in the Trilk et al. (2011) study were sedentary overweight/obese women, so it is not surprising cardiorespiratory fitness increased in these participants considering that it was low to begin with. In the McGarr et al. (2014) study, participants had higher baseline $\dot{V}O_{2peak}$ on average (~47 mL/kg/min) compared to the present investigation (Table 1). It is surprising that the less fit participants in the present study did not improve $\dot{V}O_{2peak}$. Perhaps lower volume in the present study (6 SIT sessions vs. 8 SIT sessions) explains the lack of improvement in $\dot{V}O_{2peak}$ compared to McGarr et al. (2014). Likewise, Rodas et al. (2000) employed daily sessions of multiple repetitions of all-out sprints over the course of two weeks, so the overall volume of training was greater than that used in the present study, hence a possible explanation for the improvement in $\dot{V}O_{2peak}$ in that study compared to the present one.

In terms of outcome measures associated with heat acclimation, our findings are similar to those of others who have investigated heat acclimation adaptations associated with SIT (McGarr et al., 2014). For example, McGarr et al. (2014) found a small but significant reduction in HR (main effect) during a 60-min heat stress test after eight days of SIT, but visual inspection of their data shows that participants began the heat stress test at a lower HR (~9 beats/min) post-SIT, and final HR was essentially the same, which is consistent with our findings. Differences between the present study and that of McGarr et al. (2014) include (1) the use of less aerobically fit participants, (2) the inclusion of local sweat rate assessment, and (3) performance of SIT in a hot environment by a subset of subjects in the current study. Therefore, our findings extend those of McGarr et al. (2014) by demonstrating that (1) untrained subjects—thought to have lower baseline levels of acclimation because of their physically inactive lifestyle—did not respond to the training regimen, (2) not only was whole-body sweat rate unaffected by the SIT protocol, onset threshold and sweat sensitivity were also unaffected, and (3) subjects who performed SIT in 40 °C responded no differently from subjects who performed SIT in 24 °C. Apparently, SIT performed for six sessions in hot conditions, with higher skin temperatures, is not a sufficient stimulus to result in heat acclimation adaptations.

The mechanism for heat acclimation adaptations has historically been attributed to chronic exposure to elevated core body temperature (Avellini et al., 1982; Piwonka, Robinson, Gay, & Manalis, 1965) and, to a lesser extent, skin temperature (Regan et al., 1996). During the SIT sessions, our participants experienced increases in T_{re} of 0.5 ± 0.2 °C (0.6 ± 0.2 °C for hot group and 0.4 ± 0.1 °C for temperate group) from baseline to the end of the last WAnT on the first day of SIT and 0.8 ± 0.2 °C (0.9 ± 0.1 °C for hot group and 0.7 ± 0.3 ℃ for temperate group) from baseline to the end of the last WAnT on the final day of SIT. Prior to our study, it was uncertain how much core temperature would increase during SIT bouts, especially those performed in the heat, because this information was not reported by McGarr et al. (2014), and another study involving short-term heat acclimation that had reported core temperature responses had used different intensities and durations of exercise (Kelly et al., 2016). Therefore, it was uncertain if SIT performed in the heat would provide a sufficient stimulus to promote heat acclimation. The increases we observed were lower than those (~1 °C) of other studies that have shown heat acclimation adaptations associated with elevated core body temperatures (Avellini et al., 1982; Regan et al., 1996). Our participants not only experienced smaller increases in core temperature than those in the cited studies, they also were exposed to these elevated core temperatures for less time; SIT sessions lasted ~30–40 min (total time including warm-up, etc.), but only a portion of this time was spent exercising with elevated core body temperature. Nonetheless, bouts as short as 30–35 min performed at a lower intensity (75% $\dot{V}O_{2max}$) than that used in the present study but in a similar environment (40 °C) have been shown to induce heat acclimation adaptations (Houmard et al., 1990); therefore, it was reasonable to hypothesize that our stimulus would have been sufficient.

A limitation of the current study is that exercise intensity during the pre- and post-SIT heat acclimation tests was based on $\%\dot{V}O_{2peak}$ rather than a standardized rate of metabolic heat production. The protocol was modeled after Roberts et al. (1977) since they had shown this assessment was sensitive to thermoregulatory adaptations associated with ten days of exercise training. That said, this approach has been criticized because it can confound interpretation of results because of differences in $\dot{V}O_2$ between pre- and post-training heat acclimation assessments (Stapleton, Gagnon, & Kenny, 2010). Because our participants' $\dot{V}O_{2peak}$ was unchanged by the SIT training, they exercised on average at similar absolute $\dot{V}O_2$ and power output during pre- and post-SIT heat acclimation exercise tests (Table 1). Despite comparable power outputs, some participants experienced lower absolute $\dot{V}O_2$ post-SIT compared to pre-SIT, so metabolic heat production was lower. Nevertheless, the tests of our hypotheses were likely unaffected because if the training protocol had indeed induced heat acclimation, values for T_{re}, $\bar{T}_b$, local sweat rate, and HR would have been expected to be smaller post-SIT relative to pre-SIT (because of lower metabolic heat production), but this was not the case. Therefore, our conclusion that the SIT protocol used did not produce heat acclimation seems appropriate based on our data. Another limitation is that the participants were tested in the southeastern United States when average daily high temperatures progress from ~31 °C to ~15 °C as the season shifts from fall to early winter, so they may have had some natural acclimatization. Since they were physically inactive, however, their exposure to these temperatures would have been passive and irregular.

In conclusion, two weeks of SIT performed by untrained men did not result in heat acclimation, likely because the overall exposure to elevated core body and skin temperatures—even when performed in the heat—was insufficient to induce adaptations. Furthermore, six sessions of SIT using the protocol in this study did not result in sufficient volume to improve cardiorespiratory fitness in young, physically inactive men. Collectively, findings from prior studies (McGarr et al., 2014) and the present study indicate that practitioners desiring to heat acclimate low to moderately fit individuals in a short period of time will need to induce elevations in core and skin temperatures sustained for longer durations. Future studies should determine if SIT performed using an alternative regimen (e.g., multiple SIT bouts per day and/or SIT bouts performed on sequential days) in hot and temperate conditions would be effective in inducing heat acclimation.

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