Heat Training Efficiently Increases and Maintains Hemoglobin Mass and Temperate Endurance Performance in Elite Cyclists

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ABSTRACT

RØNNESTAD, B. R., T. URIANSTAD, H. HAMARSLAND, J. HANSEN, H. NYGAARD, S. ELLEFSEN, D. HAMMARSTRÖM, and C. LUNDBY. Heat Training Efficiently Increases and Maintains Hemoglobin Mass and Temperate Endurance Performance in Elite Cyclists. *Med. Sci. Sports Exerc.*, Vol. 54, No. 9, pp. 1515–1526, 2022. **Purpose and Methods:** To test whether heat training performed as 5 × 50-min sessions per week for 5 wk in a heat chamber (CHAMBER) or while wearing a heat suit (SUIT), in temperate conditions, increases hemoglobin mass (Hb_{mass}) and endurance performance in elite cyclists, compared with a control group (CON-1). Furthermore, after the 5-wk intervention, we tested whether three sessions per week for 3 wk with heat suit ($SUIT_{main}$) would maintain Hb_{mass} elevated compared with athletes who returned to normal training ($HEAT_{stop}$) or who continued to be the control group (CON-2). **Results:** During the initial 5 wk, SUIT and CHAMBER increased Hb_{mass} (2.6% and 2.4%) to a greater extent than CON-1 (−0.7%; both $P < 0.01$). The power output at 4 mmol·L^{-1} blood lactate and 1-min power output (W_{max}) improved more in SUIT (3.6% and 7.3%, respectively) than CON-1 (−0.6%, $P < 0.05$; 0.2%, $P < 0.01$), whereas this was not the case for CHAMBER (1.4%, $P = 0.24$; 3.4%, $P = 0.29$). However, when SUIT and CHAMBER were pooled this revealed a greater improvement in a performance index (composed of power output at 4 mmol·L^{-1} blood lactate, W_{max}, and 15-min power output) than CON-1 (4.9% ± 3.2% vs 1.7% ± 1.1%, respectively; $P < 0.05$). During the 3-wk maintenance period, $SUIT_{main}$ induced a larger increase in Hb_{mass} than $HEAT_{stop}$ (3.3% vs 0.8%; $P < 0.05$), which was not different from the control (CON-2; 1.6%; $P = 0.19$), with no differences between $HEAT_{stop}$ and CON-2 ($P = 0.52$). **Conclusions:** Both SUIT and CHAMBER can increase Hb_{mass}, and pooling SUIT and CHAMBER demonstrates that heat training can increase performance. Furthermore, compared with cessation of heat training, a sustained increase in Hb_{mass} was observed during a subsequent 3-wk maintenance period, although the number of weekly heat training sessions was reduced to 3. **Key Words:** ATHLETIC PERFORMANCE, BLOOD VOLUME, ENDURANCE TRAINING, HEAT ACCLIMATIZATION, RED BLOOD CELL VOLUME

Aerobic exercise performance relies partly on a high maximal oxygen uptake ($\dot{V}O_{2max}$), which in turn is associated with a high hemoglobin mass (Hb_{mass}) (1). Although Hb_{mass} is increased with endurance training (2), complementary strategies may be valuable to further augment Hb_{mass} and thereby potentially also improve endurance performance. One such strategy could be the inclusion of heat stress in endurance training, as recent studies suggest that endurance training conducted in the heat may favor the expansion of Hb_{mass} (3–5).

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Physiological adaptations to heat exposure have been studied in humans for at least a century, including its effects on blood volume (BV). Already in the 1950s, it was observed in 72 students that plasma volume (PV) increased with ~5% during the warm summer and decreased during the cold winter (6). Interestingly, the red blood cell volume (RBCV) and circulating hemoglobin varied similarly to PV, indicating that environmental temperature affects PV and erythropoietic activity. It has been observed that if humans reside in their habitual (temperate) environment and at the same time perform heat endurance training, PV expansion occurs within less than 10 d (7). With more prolonged heat training (5 wk), an expansion of Hb_{mass} has also been observed (3,4), although not consistently associated with improved endurance performance (3–5,8). After high altitude–induced increase in RBCV, it has been observed a rather rapidly restoration of RBCV to prealtitude conditions (9). To our knowledge, the sustainability of heat training–induced increases in Hb_{mass} after withdrawing from heat training has not been investigated. Neither are we aware of studies investigating if maintenance of heat training stimulus (a reduced heat training frequency) affects the residual effect of heat training.

TABLE 1. Participant characteristics and physiological parameters determined during an incremental maximal exercise test, for heat chamber (CHAMBER), heat suit (SUIT), and the control group (CON-1) as well as mean weekly distribution of training in different intensity zones, strength training, total training volume, number of maximal strength sessions, and perceived feeling of well-being during the first 5 wk of the intervention period.

	CHAMBER	SUIT	CON-1	*P*
Age (yr)	20.2 ± 4.0	22.2 ± 7.2	18.8 ± 2.5	
Body mass (kg)	68.6 ± 7.6	68.3 ± 5.7	73.8 ± 7.1	
Body height (cm)	178.7 ± 5.7	179.5 ± 6.1	184.4 ± 5.3	
$\dot{V}O_{2max}$ (mL·min^{-1})	5311 ± 561	5293 ± 353	5578 ± 557	
$\dot{V}O_{2max}$ (mL·min^{-1}·kg^{-1})	77.5 ± 4.3	77.8 ± 5.7	75.4 ± 3.2	
W_{max} (W)	440 ± 44	437 ± 29	469 ± 52	
W_{max} (W·kg^{-1})	6.4 ± 0.4	6.4 ± 0.6	6.4 ± 0.3	
Training characteristics				
Zone 1 (h:min)	08:49 ± 03:23	07:54 ± 03:28	09:07 ± 01:35	0.609
Zone 2 (h:min)	01:35 ± 00:56	01:51 ± 01:40	01:03 ± 00:44	0.289
Zone 3 (h:min)	01:14 ± 00:47	01:07 ± 00:44	01:00 ± 00:35	0.725
Zone 4 (h:min)	00:43 ± 00:36	00:51 ± 00:24	00:40 ± 00:18	0.604
Zone 5 (h:min)	00:22 ± 00:24	00:13 ± 00:10	00:18 ± 00:13	0.416
Strength training (h:min)	01:17 ± 01:21	00:45 ± 00:56	01:34 ± 00:31	0.170
Total training volume (h:min)	14:01 ± 04:39	12:41 ± 03:05	13:40 ± 02:20	0.653
Maximal strength sessions (*n*)	0.78 ± 0.91	0.71 ± 1.01	0.69 ± 0.71	0.980
Perceived well-being (1–9)	4.62 ± 0.49	4.65 ± 0.53	4.34 ± 0.79	0.170

Values are mean ± SD.

Previous heat training studies focusing on hematological adaptations have typically been performed either by translocating temperate-adapted athletes to a warmer outdoor training environment (5) or by performing some of the training in heat chambers (3,4,7). These approaches are both time consuming and expensive, and can be challenging to integrate with all the other important training of elite endurance athletes. A possible practical and cost-effective alternative may be to apply garments that retain the heat produced during exercise training (heat suit). Indeed, a few studies have observed that exercise in heat chamber and exercising with a heat suit in temperate conditions induces similar physiological responses (10–12), and in a recent case study, we documented the feasibility of heat suit training to increase Hb_{mass} even in champion athletes (13,14). However, a heat suit limits sweat evaporation with a theoretically higher skin temperature than during heat chamber exercise. Increasing skin temperature can reduce maximal oxygen consumption ($\dot{V}O_{2max}$), increase the relative exercise intensity, and induce faster fatigue despite only modest increases in core temperature (15,16), possibly inducing different adaptations than heat chamber training. To the best of our knowledge, the effect of heat suit training and heat chamber training on hematological and physiological variables has not previously been compared.

The aims of the present study were to 1) test the hypothesis that heat stress induced by wearing heat-suit garment during endurance exercise training in temperate conditions (SUIT) induces similar adaptations as endurance training performed in a heat chamber (CHAMBER), 2) test the hypothesis that CHAMBER and SUIT improve indicators of endurance performance in temperate conditions, and 3) test the hypothesis that 3 wk of maintenance heat training with heat suit ($SUIT_{main}$; three weekly sessions), performed after the main intervention, maintains the elevated Hb_{mass} compared with cyclists returning to normal training ($HEAT_{stop}$) or continuing to act as controls (CON-2).

METHODS

Participants. Thirty-eight male cyclists age 20.4 (SD, 5.0) yr were initially recruited to participate in this study. Because of personal reasons unrelated to the study intervention, three participants withdrew from the study. All participants had undertaken their usual off-season training before the project (1042 (0408) h of training per week recorded during the 4 wk preceding pretesting) and had a history of 5.0 (2.5) yr of competitive cycling. All cyclists were categorized as performance level 4 to 5 (17), equal to being elite (18). Subject characteristics and physiological parameters are presented in Tables 1, 2, and 3. Before enrollment into the study, participants were made fully aware of the possible risks and discomforts associated with participation and gave their written informed consent to participate. The study was approved by the local ethical committee at Lillehammer University College (MR13102019) and performed in accordance with the ethical standards established by the Helsinki Declaration of 1975, including preregistration in a public Norwegian database (Norwegian Center for Research, project number 952354).

Overall study design. For the first 5-wk period of the study, all cyclists were divided into (i.e., not randomized) one of three groups based on $\dot{V}O_{2max}$ from the PRE testing and age to have similar PRE values in all groups: CHAMBER (n = 13), SUIT (n = 12), and a control group (CON-1; n = 13). During this 5-wk period, there were no significant differences in the training stimuli between groups (Table 1). One participant in CON-1 completed the hematological testing only, and as such, hematological analyses are based on data from 35 participants, whereas all other analyses are based on data

TABLE 2. Heat session data during the initial 5-wk intervention period, presented as weekly average data collected during and after each session for the cyclists training in a heat chamber (CHAMBER) or in a heat suit in temperate conditions (SUIT).

	Week 1		Week 2		Week 3		Week 4		Week 5	
Variable	SUIT	CHAMBER	SUIT	CHAMBER	SUIT	CHAMBER	SUIT	CHAMBER	SUIT	CHAMBER
Room temperature (°C)	17.6 (0.1)	35.2 (0.0)^a	18.2 (0.3)	35.1 (0.1)^a	20.7 (1.1)	35.1 (0.1)^a	21.1 (1.3)	35.2 (0.1)^a	21.9 (0.7)	35.1 (0.1)^a
RH (%)	38.7 (0.1)	62.8 (1.3)^a	32.4 (1.7)	61.9 (0.8)^a	34.3 (2.5)	61.9 (1.5)^a	43.3 (2.7)	60.3 (0.8)^a	38.5 (2.1)	59.9 (0.8)^a
Power output (W)	154 (8)	134 (16)^a	161 (9)	135 (16)^a	162 (7)	133 (19)^a	157 (12)	134 (17)^a	156 (13)	135 (16)^a
HR (bpm)	142 (8)	145 (10)	140 (7)	139 (10)	141 (6)	139 (9)	142 (8)	137 (9)	141 (5)	136 (9)
Blood lactate (mmol·L^{-1})	0.86 (0.11)	0.81 (0.15)	0.74 (0.14)	0.88 (0.13)	0.87 (0.30)	0.74 (0.18)	0.63 (0.12)	0.75 (0.13)	0.69 (0.27)	0.74 (0.09)
Rectal temperature (°C)	38.5 (0.3)	39.1 (0.3)^a	38.4 (0.2)	38.9 (0.3)^a	38.6 (0.1)	38.9 (0.2)^a	38.6 (0.2)	38.8 (0.3)	38.6 (0.1)	38.9 (0.3)^a
Fluid loss (L)	−1.36 (0.32)	−1.42 (0.38)	−1.42 (0.17)	−1.52 (0.33)	−1.68 (0.19)	−1.57 (0.42)	−1.76 (0.26)	−1.67 (0.37)	−1.68 (0.29)	−1.72 (0.31)
RPE (6–20)	12.3 (0.9)	12.4 (1.1)	11.7 (0.5)	11.5 (1.4)	12.1 (0.8)	11.3 (1.1)	11.9 (0.9)	11.2 (1.1)	11.6 (0.7)	11.1 (1.2)
Session RPE (1–10)	3.36 (0.87)	3.83 (0.88)	2.89 (0.73)	3.19 (0.58)	3.23 (0.79)	3.10 (0.57)	3.13 (0.97)	2.83 (0.54)	2.94 (0.67)	2.98 (0.58)
Thermal sensation (0–8)	6.13 (0.43)	6.08 (0.51)	5.87 (0.28)	5.66 (0.57)	6.05 (0.34)	5.55 (0.56)^a	6.04 (0.41)	5.40 (0.62)^a	5.93 (0.33)	5.35 (0.58)^a

Values are mean (SD).
^{a}Different from SUIT at the current time point (P < 0.05).

TABLE 3. Data from the submaximal and maximal incremental exercise, and 15-min cycling tests before (Pre) and after the initial 5-wk intervention period (MID) for the cyclists training in a heat chamber (CHAMBER) or in a heat suit in temperate conditions (SUIT), and the two heat training group pooled (HEAT) and the control group (CON-1).

	CON-1		SUIT		CHAMBER		Group Comparisons			
Variable	Pre	Mid	Pre	Mid	Pre	Mid	ΔSuit vs ΔCON-1 (%)	ΔChamber vs ΔCON-1 (%)	ΔChamber vs ΔSuit (%)	ΔHEAT vs ΔCON-1 (%)
Body mass (kg)	74.0 (7.4)	74.0 (7.7)	68.3 (5.7)	68.0 (5.4)	68.6 (7.6)	69.0 (7.4)	−0.3 [−1.8, 1.2]	0.6 [−0.8, 2.1]	0.9 [−0.5, 2.4]	0.2 [−1.0, 1.4]
Submaximal exercise test										
$Power_{4\ mmol \cdot L^{-1}}$ (W)	325 (41)	323 (41)	302 (20)	313 (27)	295 (36)	299 (32)	4.1 [0.0, 8.4][a]	2.3 [−1.6, 6.4]	−1.7 [−5.5, 2.2]	3.2 [−0.2, 6.7]
$[La^-]_{fresh}$ ($mmol \cdot L^{-1}$)	1.71 (0.42)	1.66 (0.34)	1.76 (0.40)	1.58 (0.41)	1.63 (0.30)	1.54 (0.31)	−9.0 [−22.7, 7.2]	−3.5 [−17.4, 12.8]	6.0 [−9.7, 24.4]	−6.0 [−17.6, 7.2]
$[La^-]_{fatigue}$ ($mmol \cdot L^{-1}$)	1.91 (0.50)	2.04 (0.56)	1.88 (0.41)	2.17 (0.60)	1.80 (0.46)	1.84 (0.67)	7.2 [−18.4, 40.9]	−8.2 [−28.8, 18.4]	−14.4 [−34.1, 11.2]	−1.9 [−21.2, 22.2]
GE_{fresh} (%)	19.2 (0.6)	19.1 (0.8)	19.3 (0.9)	19.7 (1.2)	19.0 (0.8)	19.2 (0.7)	2.1 [−0.9, 5.2]	1.4 [−1.6, 4.4]	−0.7 [−3.7, 2.3]	1.7 [−0.7, 4.2]
$GE_{fatigue}$ (%)	18.7 (1.0)	18.8 (1.0)	18.4 (0.9)	18.9 (1.1)	18.1 (0.9)	18.3 (0.7)	2.4 [0.0, 4.7][a]	0.7 [−1.5, 2.9]	−1.7 [−3.8, 0.6]	1.4 [−0.5, 3.3]
Maximal exercise test										
$\dot{V}O_{2max}$ ($mL \cdot min^{-1}$)	5578 (557)	5630 (538)	5293 (353)	5443 (269)	5311 (561)	5466 (591)	1.9 [−1.2, 5.1]	1.9 [−1.2, 5.0]	−0.0 [−3.0, 3.0]	1.9 [−0.6, 4.5]
$\dot{V}O_{2max}$ ($mL \cdot kg^{-1}\ min^{-1}$)	75.4 (3.2)	76.2 (2.9)	77.8 (5.7)	80.3 (4.3)	77.5 (4.3)	79.3 (3.5)	2.2 [−1.2, 5.8]	1.3 [−2.1, 4.8]	−1.0 [−4.3, 2.5]	1.7 [−1.1, 4.6]
RER_{max}	1.15 (0.03)	1.16 (0.04)	1.16 (0.04)	1.17 (0.05)	1.15 (0.03)	1.16 (0.04)	0.1 [−2.2, 2.5]	−0.8 [−3.0, 1.5]	−0.9 [−3.1, 1.4]	−0.4 [−2.2, 1.6]
VE_{max} ($L \cdot min^{-1}$)	203 (14)	208 (14)	208 (20)	215 (19)	200 (20)	203 (18)	1.1 [−1.8, 4.1]	−0.7 [−3.5, 2.2]	−1.8 [−4.6, 1.1]	0.1 [−2.3, 2.6]
HR_{max} (bpm)	200 (6)	198 (5)	197 (8)	197 (9)	196 (8)	195 (7)	0.4 [−1.3, 2.2]	−0.8 [−2.5, 1.0]	−1.2 [−2.9, 0.5]	−0.2 [−1.7, 1.3]
$Lactate_{max}$ ($mmol \cdot L^{-1}$)	11.3 (3.9)	13.5 (2.1)	12.8 (2.6)	14.3 (2.5)	13.6 (1.5)	14.0 (2.1)	−18.2 [−43.7, 18.9]	−24.9 [−47.6, 7.7]	−8.2 [−36.0, 31.7]	−21.8 [−42.0, 6.1]
RPE_{max}	19.5 (0.7)	19.6 (0.5)	19.3 (0.5)	19.7 (0.5)	19.4 (0.5)	19.6 (0.5)	1.4 [−1.2, 4.0]	−0.1 [−2.6, 2.4]	−1.5 [−3.9, 1.0]	0.6 [−1.5, 2.8]
W_{max}	470 (52)	478 (56)	437 (28)	469 (25)	440 (44)	455 (48)	5.7 [2.1, 9.5][a]	1.8 [−1.6, 5.4]	−3.7 [−6.9, −0.4][a]	3.7 [0.5, 6.9][a]
15-min cycling trial										
Power output (W)	342 (51)	356 (50)	304 (26)	333 (20)	318 (39)	333 (40)	5.1 [−0.4, 10.9]	0.6 [−4.5, 5.9]	−4.3 [−9.2, 0.9]	2.6 [−1.9, 7.3]
HR_{mean} (bpm)	183 (5)	184 (5)	183 (8)	182 (8)	183 (7)	179 (5)	−0.9 [−3.2, 1.5]	−3.0 [−5.2, −0.6][a]	−2.1 [−4.5, 0.4]	−1.9 [−3.9, 0.0]
$[La^-]$ ($mmol \cdot L^{-1}$)	7.42 (2.55)	10.6 (4.4)	8.49 (3.72)	11.2 (2.9)	9.09 (3.46)	10.2 (2.6)	2.1 [−31.7, 52.7]	−19.3 [−45.5, 19.3]	−21.0 [−46.6, 16.8]	−9.9 [−35.2, 25.3]
RPE	19.3 (0.8)	18.8 (2.4)	19.4 (0.9)	19.7 (0.5)	19.4 (0.7)	19.4 (0.7)	4.6 [−4.9, 15.1]	3.4 [−5.8, 13.5]	−1.1 [−10.1, 8.7]	4.0 [−3.5, 12.0]
Leg press peak power (W)	1549 (299)	1535 (285)	1330 (238)	1291 (202)	1419 (252)	1415 (258)	−1.8 [−7.7, 4.4]	0.5 [−5.4, 6.8]	2.4 [−3.7, 8.8]	−0.6 [−5.6, 4.5]

Descriptive data are mean (SD). Group comparisons show differences in change scores (%-points) between groups with 95% CI.

[a]A 95% CI not containing null.

HR_{max}, maximal HR; $[La^-]_{max}$, maximal blood lactate concentration 1 min after exercise; $[La^-]_{fatigue}$ and $GE_{fatigue}$, blood lactate concentration and gross economy at the power output from the second last bout of the blood lactate profile after the prolonged cycling; $[La^-]_{fresh}$ and GE_{fresh}, blood lactate concentration and gross economy at the second last bout of the blood lactate profile; $Power_{4\ mmol \cdot L^{-1}}$, power output at a blood lactate concentration of 4 $mmol \cdot L^{-1}$; RER_{max}, maximal RER; RPE_{max}, maximal RPE; VE_{max}, maximal ventilation.

APPLIED SCIENCES

from 34 participants. After the initial 5-wk intervention period, laboratory tests were conducted (MID), and thereafter, the study was continued for another 3 wk. During this period, a total of 11 participants from the two heat training groups (i.e., a combination of subjects from CHAMBER and SUIT) continued with heat maintenance training consisting of three weekly training sessions wearing heat suits ($SUIT_{main}$), whereas 11 other participants from the same heat training groups stopped their heat training ($HEAT_{stop}$). At the same time, 10 participants from the CON-1 group continued their normal training (CON-2; Fig. 1). Participant characteristics from the initial 5-wk intervention and the subsequent 3-wk maintenance period are shown in Table 1 and in the Supplemental Table (Supplemental Digital Content, Participant characteristics and training data, http://links.lww.com/MSS/C568). There were no significant differences in the training stimuli between groups after regrouping (Supplemental Table, Supplemental Digital Content, Participant characteristics and training data, http://links.lww.com/MSS/C568). From 2 wk before the start of the intervention to after the intervention, all cyclists ingested 100 mg oral iron supplement on a daily basis (Nycoplus Ferro-Retard 100 mg; Takeda AS, Asker, Norway) to ensure adequate iron levels for erythropoiesis.

Training intervention. Both CHAMBER and SUIT performed heat sessions in the afternoon, five times per week during the first 5 wk using their own bicycle mounted on a stationary power trainer (Tacx Neo Smart Trainer, Wassenaar, the Netherlands). CHAMBER and SUIT were instructed to cycle for the whole session at a power output corresponding to between ~45% and ~51%, respectively, of individual power output at 4 $mmol \cdot L^{-1}$ [La^-] in temperate conditions (Table 2). The slightly higher power output in SUIT was due to pilot testing, indicating that this was needed to reach the target rectal temperature. During heat training sessions, participants in the SUIT group were wearing clothing that limited heat loss, consisting of a wool layer on both the upper and lower bodies, a wool hat, nylon rain jacket, down jacket, and nylon pants with poor evaporative capacity. During heat sessions, both CHAMBER and SUIT were instructed to drink 0.5 L of water. All training sessions were supervised, and room temperature, relative humidity (RH), heart rate (HR; measured with personal HR monitors), rate of perceived exertion (RPE; 6–20 scale) (19), thermal sensation (0–8 scale) (20), and power output were recorded after 5, 10, 15, 20, 30, 40, and 50 min (Table 2). If necessary, power output for both the CHAMBER and SUIT groups was adjusted to reach a rectal temperature of ≥38.5°C at the end of each session. Power output was increased by 25 W for the next session if RPE after finishing exercise was <11 or reduced by 20 W if RPE was >15. Ten minutes after each session, the participants rated their session RPE 1–10 scale (sRPE; Table 2) (21). Participants were instructed to maintain their normal training throughout the intervention but subtract the additional hours of heat training to not increase their total training volume.

During the 5-wk training intervention, there were no differences between CHAMBER, SUIT, and CON-1 in mean weekly duration of the endurance training and the distribution of this training into a five-zone intensity scale (Table 1), based on percentage of functional threshold power (FTP): zone 1 (<55% FTP), zone 2 (56%–75% FTP), zone 3 (76%–90% FTP), zone 4 (91%–105% FTP), and zone 5 (106%–120% FTP). There were no differences between the groups in mean duration of strength training (Table 1). In the subsequent 3-wk maintenance

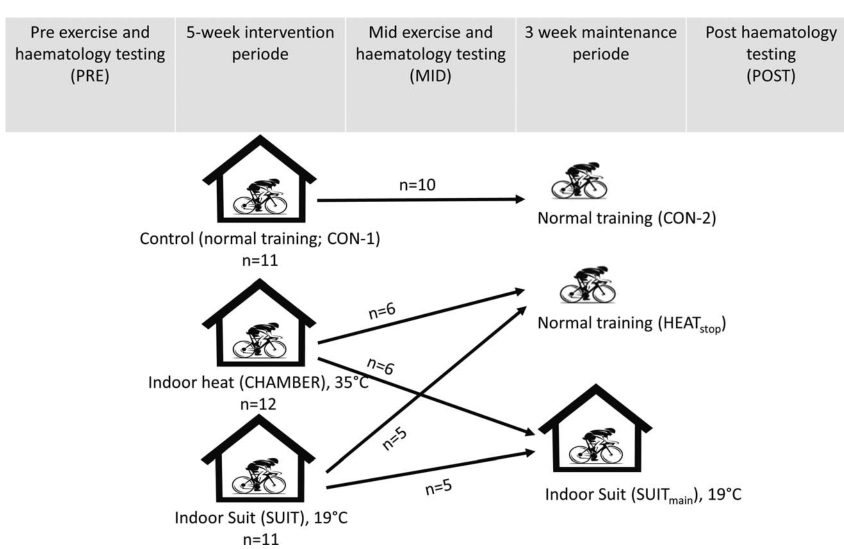

FIGURE 1—Study participants underwent laboratory testing before the intervention (PRE) after which they were assigned to one of three intervention groups: 1) control (CON-1) where participants conducted normal training, 2) indoor heat (CHAMBER) where participants trained at an ambient temperature of 35°C and 60%–63% humidity while wearing normal short cycling clothing, and 3) a group that trained indoor at 19°C while wearing a heat suit (SUIT). Irrespective of heat exercise group allocation, all five (Monday–Friday) weekly heat training sessions were 50 min in duration. Laboratory tests were performed after completion of 5 wk of training intervention (MID). After testing, heat group participants were divided into one of two groups: 1) a group that returned to normal training only and stopped heat training ($HEAT_{stop}$) and 2) a group that performed indoor training (19°C) while wearing a heat suit ($SUIT_{main}$) three times a week, whereas the control group simply continued to be a control (CON-2). After the 3-wk maintenance period, all participants underwent hematological testing (POST). All cycle performance testing was conducted at 18°C.

period, there were no significant differences between groups in time in the different intensity zones (Supplemental Table, Supplemental Digital Content, Participant characteristics and training data, http://links.lww.com/MSS/C568).

Exercise test protocol. During the 2 d preceding the testing before and after the 5-wk intervention, training was standardized and similar between all groups. During the first visit to the laboratory, all cyclists reported their three last meals and fluid intake and their training during the 48 h before the test. Three days before the test after the 5-wk intervention, a message was sent to each of the participants with a notification of their training and nutritional preparations before pretest and the instructions to repeat this to ensure comparable preparations. Nutritional energy intake during the entire test at pre was also noted and replicated at posttest. All tests were performed under similar environmental conditions (16°C–19°C) with airflow of 2–3 $m \cdot s^{-1}$ toward the participants' frontal surface. Strong verbal encouragement was given during all tests to ensure maximal effort. All tests for the individual cyclists were conducted at the same time of day (±1 h) to avoid influence of circadian rhythms. All testing was performed on the same electromagnetically braked cycle ergometer (Lode Excalibur Sport; Lode B.V., Groningen, the Netherlands), which was adjusted according to each cyclist's preference for seat height, horizontal distance between tip of seat and bottom bracket, and handlebar position. Identical seating positions were used during all tests.

An overview of the test day is presented in Figure 2. After a 5-min warm-up on an ergometer cycle at an RPE of 11–12, the participants performed a leg press peak power test (Keiser AIR300 Leg Press; Keiser Corp., Fresno, CA). This test was performed to rule out that potential performance gains were associated with changes in strength, because previous studies have demonstrated that strength training can improve cycling performance (22). The participants sat with knees flexed at 90° to 96° and the hips flexed at approximately 45°, with the individual seating position being identical for pretest and posttest. Two warm-up repetitions were performed at 44 kg. The power testing consisted of a single trial of 10 lifts with increasing load and standardized recovery periods (gradually increasing from 5 to 60 s) and loads starting at 44 kg and ending at ~280 kg. During all lifts, the participants were instructed to exert force "as fast as possible." Average concentric mechanical power of each lift was calculated in the manufacturer's software, and based on these calculations, peak power output was calculated and used for statistical analysis. After a 5-min recovery, the blood lactate profile test was started.

The cycling testing started with a blood lactate profile initiated with 5-min cycling at 125 W followed by 50-W increases every 5 min. Blood was sampled from a fingertip at the end of each 5-min bout and analyzed for whole blood $[La^-]$ using a Biosen C-line lactate analyzer (EKF Diagnostic GmbH, Barlebe, Germany). When reaching a $[La^-]$ of 2 $mmol \cdot L^{-1}$, every 5-min bout increased by 25 W and the test was terminated when a $[La^-]$ of 4 $mmol \cdot L^{-1}$ or higher was measured; respiratory exchange ratio (RER) and HR were measured during the last 3 min of each bout. Metabolic strain in the fresh state was measured as gross economy (GE_{fresh}) and $[La^-]_{fresh}$ at the second last bout of the blood lactate profile. HR was measured using a Polar S610i HR monitor (Polar, Kempele, Finland). $\dot{V}O_2$ was measured (30-s sampling time) using a computerized metabolic system with mixing chamber (Oxycon Pro; Erich Jaeger, Hoechberg, Germany). The gas analyzers were calibrated with certified calibration gases of known concentrations before every test. Flow turbines (Triple V, Erich Jaeger) were calibrated before every test with a 3-L, 5530 series, calibration syringe (Hans Rudolph, Kansas City, KS). The same metabolic system with identical calibration routines was used on all subsequent tests for each participant. From this cycling test, power output at 4 $mmol \cdot L^{-1}$ $[La^-]$, a common measure for lactate threshold power, was calculated. GE was calculated by the oxygen equivalent (23) and the matching RER values to establish the energy expended $\dot{V}O_2$ $(L \cdot s^{-1}) \times (4840\ J \cdot L^{-1} \times RER + 16{,}890\ J \cdot L^{-1})$ (24), and this was divided by the power output and multiplied by 100.

After termination of the blood lactate profile test, the cyclists had 5 min of recovery before completing another incremental cycling test for determination of $\dot{V}O_{2max}$. The incremental test

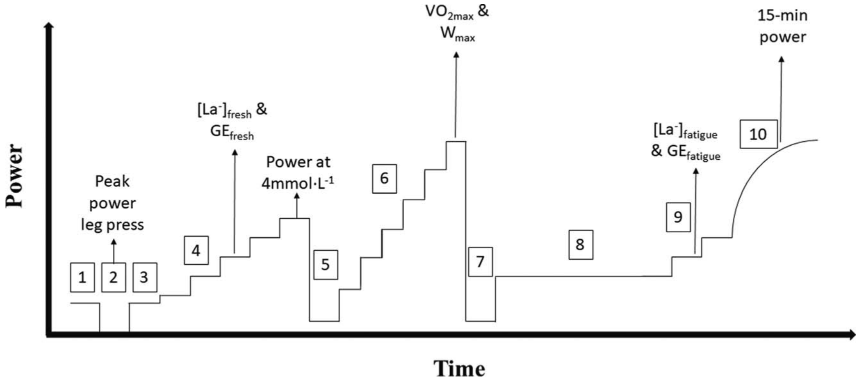

FIGURE 2—Study exercise test flowchart. The exercise tests consisted of a number of different tests all conducted in continuum and within the same day: 1) 5-min warm-up, 2) peak power leg press, 3) 5-min easy cycling, 4) lactate profile test, 5) 5-min rest/easy cycling, 6) $\dot{V}O_{2max}$ test, 7) 5-min rest/easy cycling, 8) 30 min at power output equal to 2.0 $mmol \cdot L^{-1}$ $[La^-]$, 9) 5-min bouts at power output equal to third and second last workload from lactate profile test to asses these measurement in a semifatigued state, and 10) 15-min all-out. The overall aim with the applied test battery was to evaluate exercise performance in a realistic manner while at the same time taking advantage of the controlled settings provided by an exercise laboratory.

started at 200 W (250 W if lactate threshold >325 W). Power output was subsequently increased by 25 W every minute until exhaustion, defined as a cadence less than 60 rpm. $\dot{V}O_{2max}$ was calculated as the average of the two highest subsequent 30-s $\dot{V}O_2$ measurements. W_{max} was calculated as the mean power output during the last minute of the incremental $\dot{V}O_{2max}$ test. After the $\dot{V}O_{2max}$ test, the cyclists had another 5-min recovery period before they started on 30-min cycling at the power at 2 mmol·L^{-1} [La$^-$] calculated from the blood lactate profile. Thereafter, the third and second last 5-min step from the blood lactate profile test was repeated. During the third last 5-min step, [La$^-$] and GE were measured to assess metabolic strain in a semifatigued state ([La$^-$]$_{fatigue}$ and GE$_{fatigue}$, respectively). The 30 min at 2 mmol·L^{-1} [La$^-$] followed by measurement of [La$^-$] and GE was performed because we previously have observed different training adaptations in GE between fresh and more fatigued states (25). A 15-min cycling performance test followed directly after the second last 5-min step from the blood lactate profile test was performed (Fig. 2). The participants were allowed to adjust the power output throughout the 15-min cycling test using an external control unit placed next to the handlebar of the Lode Excalibur Sport cycle ergometer. HR and $\dot{V}O_2$ were measured continuously during test, and performance was measured as the average power output. To more accurately reflect each individual's performance status, a performance index was calculated as the average of the main performance indicators (power at 4 mmol·L^{-1} [La$^-$], W_{max}, and 15-min power) after normalization (x_i/max(x), where x_i is a single observation from one performance indicator).

Hematology. Hb$_{mass}$ and intravascular volumes were assessed on five occasions: two preintervention (PRE) and two again upon termination of the 5-wk intervention period (MID; obtained 2 and 3 d after the last heat training session) and the last time 8 wk after pretesting (POST). The duplicate measurements before and after the 5-wk intervention were averaged and used for statistical analysis of the 5-wk intervention. All measurements were based on automated carbon monoxide rebreathing (Detalo Performance; Detalo Health, Copenhagen, Denmark). All procedures have been described in detail elsewhere (4).

Statistics and data analysis. Descriptive data are presented as mean and SD. Inferential statements about differences in change scores between groups are made based on linear mixed-effects models (fitted with the *lme4* package written for R (https://www.R-project.org/)) using custom contrasts (e.g., Δ SUIT vs Δ CHAMBER). Confidence intervals (95% CI) and P values were retrieved for each contrast using the Kenward–Roger's approximation of degrees of freedom using the *emmeans* package (https://cran.r-project.org/web/packages/emmeans/index.html). Confidence intervals (95%) not containing the null hypothesis (or corresponding P values <0.05) were considered statistically significant. The sample size was constrained by the number of available elite cyclists. This resulted in a power 74% to detect an effect in Hb$_{mass}$ change between heat treatment (n = 25) and control (n = 13) with similar magnitude as previously reported by us (4) (unpaired t-test, alpha = 0.05, effect size = 0.92). The sample size further resulted in a power of 60% to detect differences in similar magnitude between heat treatment groups (n = 12 and n = 13; unpaired t-test, alpha = 0.05, effect size = 0.92). The effect of heat treatment on performance indicators versus control is arguable of a lesser magnitude (4). Heat treatment groups were combined and compared with the control group to investigate the effect of heat on performance. Within-group changes are presented for descriptive purposes with no statistical assessment. Dependent variables were log-transformed before modeling, and residual plots were visually inspected for deviations from model assumptions.

RESULTS

Heat exposure. Overall, the two heat training modalities, CHAMBER and SUIT, induced similar sweating, HR, and RPE during heat exercise (Table 2). However, there were small group differences between groups in rectal temperature, thermal sensation, and power output ($P < 0.05$; Table 2).

Effects of heat training on hematological variables. In CHAMBER and SUIT, the 5-wk intervention with heat training led to increased Hb$_{mass}$ compared with CON-1 (CHAMBER vs CON-1: P = 0.007, SUIT vs CON-1: P = 0.005), with no difference being observed between the two heat training modalities (P = 0.86; Fig. 3A).

This was accompanied by relative increases in hematocrit (HCT; CHAMBER vs CON-1: P = 0.009, SUIT vs CON-1: P = 0.003; Fig. 3B), but not in RBCV (CHAMBER vs CON-1: P = 0.22, SUIT vs CON-1: P = 0.10; Fig. 3C), with concomitant decreases in PV (CHAMBER vs CON-1: P = 0.012, SUIT vs CON-1: P = 0.007; Fig. 3D). There were no differences between CHAMBER and SUIT in changes for any of these hematological measures. Neither of the experimental groups were associated with differential changes in total BV (CHAMBER vs CON-1: P = 0.13, SUIT vs CON-1: P = 0.18; CHAMBER vs CON-1: P = 0.87; Fig. 3E).

Effects of heat training on exercise performance. In SUIT, but not in CHAMBER, the 5-wk intervention led to improved exercise performance compared with CON-1 (SUIT vs CON-1, 4.8% (1.8, 7.8), P = 0.002; CHAMBER vs CON-1, 1.6% (−1.2, 4.4), P = 0.27; Figs. 4A, B), measured as a weighted performance index consisting of power at 4 mmol·L^{-1} [La$^-$], W_{max}, and power output during a 15-min time trial. In accordance with this, SUIT led to improved performance compared with CHAMBER (3.1% (0.3, 5.7), P = 0.029; Figs. 4A, B). After combining CHAMBER and SUIT (HEAT$_{combined}$), heat training *per se* led to improved performance compared with CON-1 (3.1% (0.5, 5.7), P = 0.023; Figs. 4A, B). Overall, the patterns of differential changes observed for the performance index between experimental groups were mirrored by changes observed for each of the underlying variables as single-standing entities (Table 3, Figs. 4C–E). For power at 4 mmol·L^{-1} [La$^-$], W_{max}, and the performance index, change scores correlated with changes in Hb$_{mass}$ (Fig. 4F).

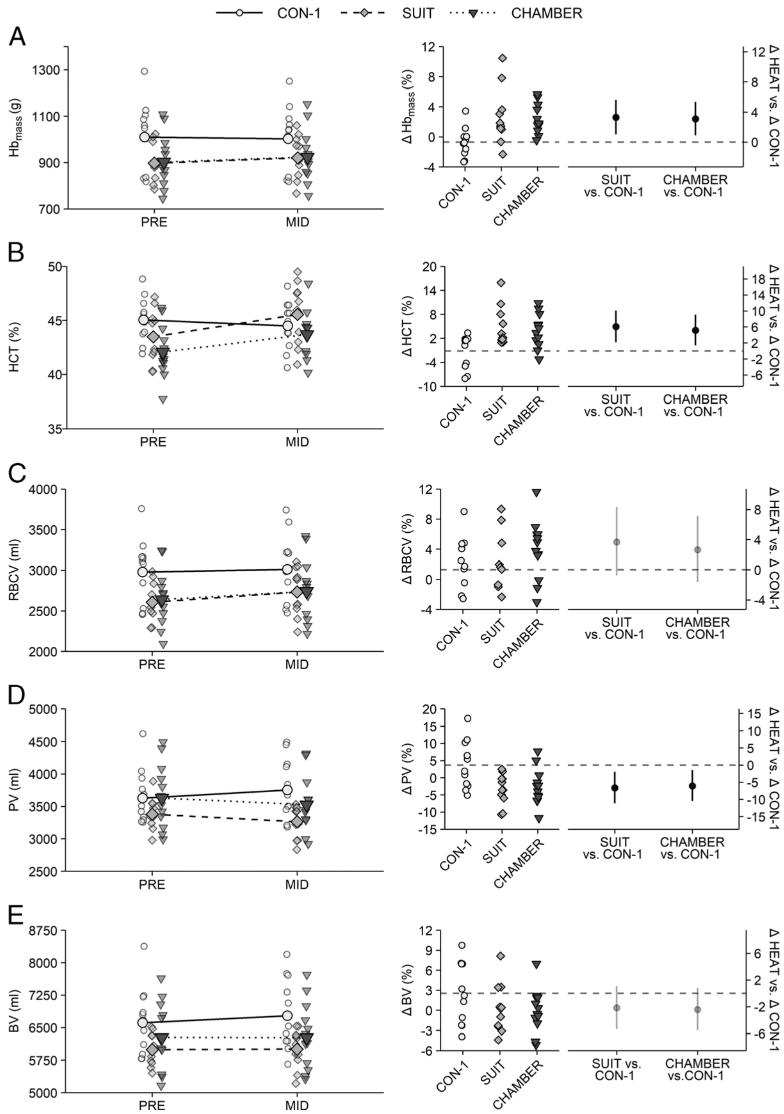

FIGURE 3—Hb_{mass} (A), HCT (B), RBCV (C), PV (D), and BV (E) before (PRE) and after (MID) the initial 5-wk intervention period in the heat suit group (SUIT), heat chamber group (CHAMBER), and the control group (CON-1). Individual values (transparent points) and group averages (solid points connected with lines) are shown in left panels. Individual percentage change scores together with group comparisons are shown in right panels. Dashed lines in right panels indicate the average change in CON-1. Error bars in right panels indicate 95% CI for the difference in change scores between the CON-1 and intervention groups (SUIT and CHAMBER). Transparent points and error bars in right panels indicate that the 95% CI contains 0.

For indices of submaximal exercise performance (other than power at 4 $mmol \cdot L^{-1}$ [La^{-}]), neither of the experimental groups were associated with differential responses, with exception of $GE_{fatigue}$, which increased in SUIT compared with CON-1 (P = 0.047; Table 3). Similarly, physiological variables collected during maximal exercise testing did not differ between groups over time (all comparisons, $P > 0.05$; Table 3). This was also the case for peak power measured in leg press (Table 3).

Effects of heat maintenance period on hematological parameters. In $SUIT_{main}$, the 3-wk maintenance period (MID to POST) led to increased Hb_{mass} compared with $HEAT_{stop}$ (P = 0.049), but not compared with CON-2 (P = 0.193), with no difference being observed between $HEAT_{stop}$ and CON-2 (P = 0.193; Fig. 5). For other hematological variables, the maintenance period was not associated with differential changes between groups (Fig. 5).

DISCUSSION

The main finding of the present study is that Hb_{mass} was elevated to a larger extent after 5 wk of both CHAMBER and SUIT compared with CON-1. Despite similar improvements in Hb_{mass}, only SUIT displayed a significant improved performance index compared with CON-1, which was also larger than CHAMBER, with CHAMBER displaying a nonsignificant trend toward an average advantage over CON-1. When pooling SUIT and CHAMBER, data revealed a larger increase in performance index than CON-1. After the 3-wk maintenance period performed after the initial 5-wk intervention period, $SUIT_{main}$ revealed a larger gain

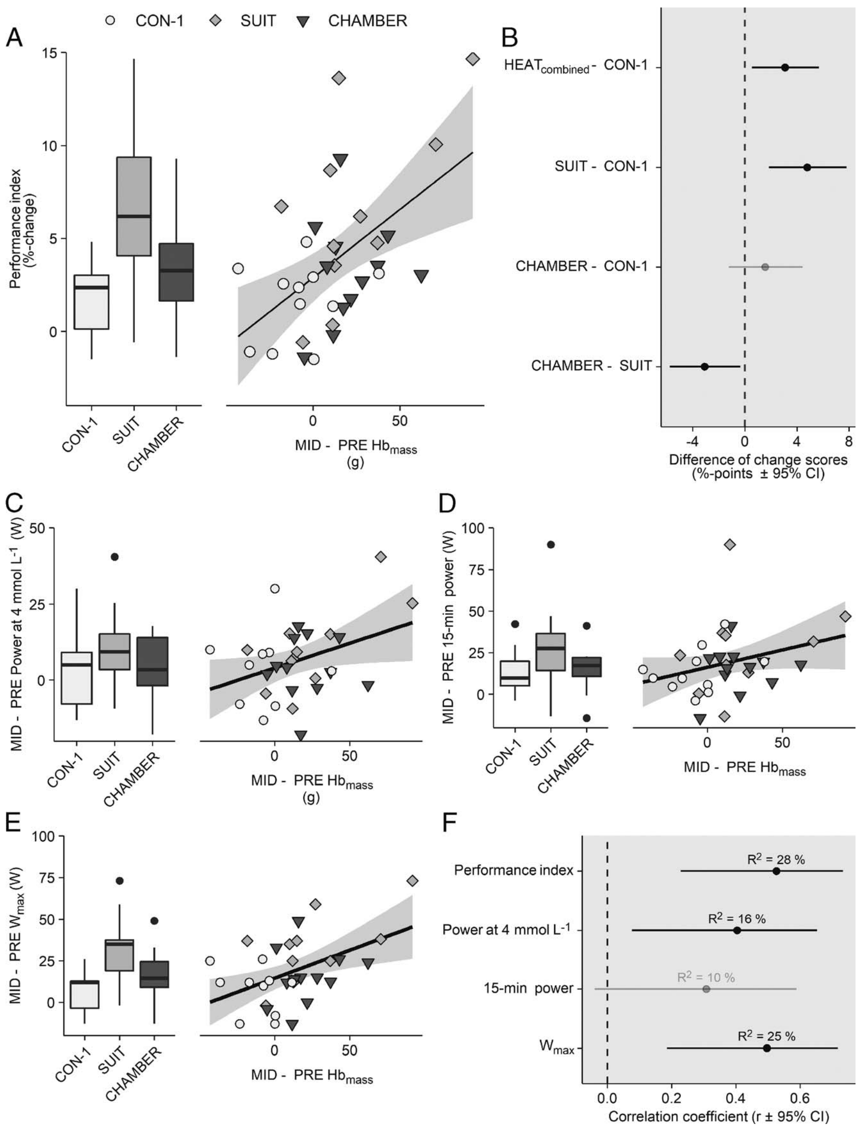

FIGURE 4—Changes in endurance performance indicators shown as a performance index (A, integrated from the three performance indicators; power output at a blood lactate concentration of 4 mmol·L^{-1} (power at 4 mmol·L^{-1}; C), mean power output during 15-min time trial (15-min power; D), maximal 1-min power output (W_{max}; E), and Hb_{mass}. Relative changes are shown in box plots for the performance index and absolute changes for individual indicators. Comparisons in panel B are pairwise comparisons of change scores in the performance index between groups. Correlation coefficients in panel F are calculated from percentage changes of performance indicators and raw change scores in Hb_{mass} and shown together with R^2 values.

in Hb_{mass} than $HEAT_{stop}$ and a nonsignificant trend toward advantage compared with CON-2, whereas there was no difference between $HEAT_{stop}$ and CON-2.

As previously observed, physiological responses like sweat rate and HR measured during each heat exercise session were overall similar between CHAMBER and SUIT (13). During most of the weeks, CHAMBER achieved a slightly larger rectal temperature than SUIT, whereas SUIT had a slightly higher heat feeling than CHAMBER. The latter might be related to a larger limitation of sweat evaporation in SUIT with a theoretically higher skin temperature than during heat chamber exercise. Increasing skin temperature can increase the relative exercise intensity despite only modest increases in core temperature (15). However, despite differences in heat feeling, there were no group differences in RPE or sRPE. This suggests that, as long as the exercise intensity and insulation properties of the heat suit are adequate, exercise conducted while wearing a heat suit in temperate conditions may be a simple and low-cost alternative to training in a heat chamber or to traveling to warm locations. The achieved heat stress in SUIT is also comparable to a similar heat chamber intervention (4). Accordingly, the hematological responses to heat training were similar in CHAMBER and SUIT, and they both displayed a greater increase in Hb_{mass} than CON-1. The latter is in line with a previous study on elite cyclists with a similar design comparing heat chamber with a control group (4). The present findings are also supported by the observed tendency toward a larger Hb_{mass} increase in endurance athletes after ≥5 wk of endurance training in heat chamber (3) or heat suit (14). Furthermore, 3-wk of postexercise sauna bathing has also been shown to increase RBCV (26). Thus, it

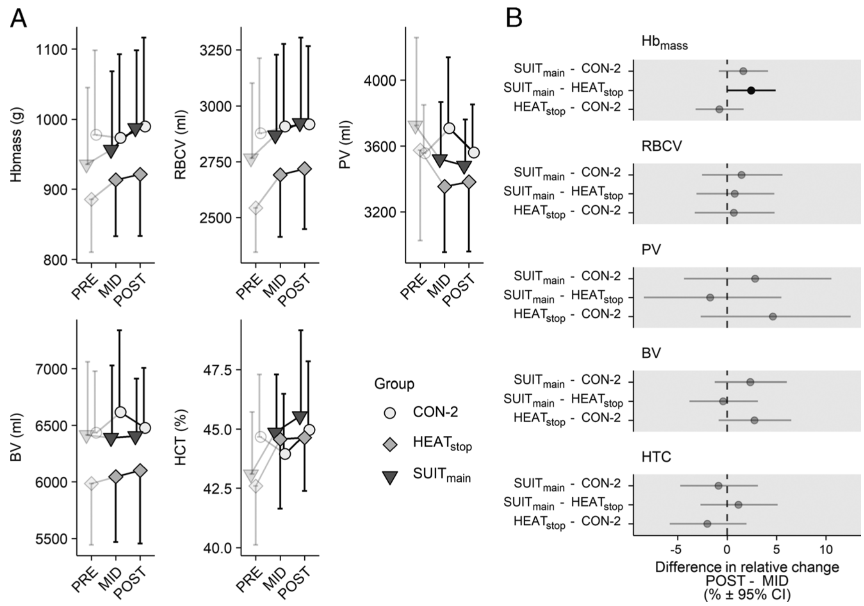

FIGURE 5—Hb$_{mass}$, RBCV, PV, BV, and HCT during the 3-wk maintenance period (MID–POST). Panel A shows group averages over the whole study period with the maintenance period highlighted (MID–POST). Error bars in panel A indicates SD. Pairwise comparisons in panel B are differences in relative change over the maintenance period. Shaded points and error bars indicate a 95% CI containing the null hypothesis.

has repeatedly been demonstrated that 5 wk with heat endurance training may increase Hb$_{mass}$ in trained to elite male athletes.

Heat endurance training is known to induce a 6%–13% increase in PV after ~10 d (7), and it has been suggested that this hypervolemia-induced reduction in HCT may trigger erythropoiesis via a critmeter function within the kidney (27) to maintain a constant HCT (3,4). Despite the increase in PV is a robust observation after short-term heat training, it is not necessarily a robust response to prolonged heat training. Indeed, we have recently performed two heat training studies wherein no difference between a heat group and a control group in PV was observed after 5 wk (3,4). However, in the present study, both CHAMBER and SUIT displayed reduced PV after the 5-wk intervention period compared with the control group. The lack of measurable effects on PV in these long-duration studies could be suggested to be a carryover effect of the last heat training session or be related to the notion that a peak in PV is present after 7–10 d, but which thereafter declines (28). The presented study was not designed to investigate mechanisms, but in addition to the critmeter hypothesis, it can be speculated that hypoxia-inducible factor and heat shock proteins can be involved in the observed effects of heat training (29,30).

Heat training and physiological determinants of endurance performance. In the present study, the increases in Hb$_{mass}$ in CHAMBER and SUIT compared with CON-1 did not induce a superior increase in $\dot{V}O_{2max}$. This may seem surprising, as there is a strong relationship between total Hb$_{mass}$ and $\dot{V}O_{2max}$, with each *g* increase in hemoglobin having been proposed to lead to 4 mL·min^{-1} increases in $\dot{V}O_{2max}$ (31). Regardless of this, the observed lack of statistical effects of heat training on $\dot{V}O_{2max}$ despite an increase in Hb$_{mass}$ is in agreement with previous studies investigating the effects of prolonged heat training (4,8), although a recent meta-analysis revealed that heat training can enhance $\dot{V}O_{2max}$ in thermoneutral environments by a small, but significant amount (32). Furthermore, $\dot{V}O_{2max}$ is influenced by factors other than Hb$_{mass}$ (1). There was an increased RBCV in both CHAMBER and SUIT, which could have a positive impact on the oxygen transport capacity by increasing BV and maximal cardiac output (and thus arguably $\dot{V}O_{2max}$) via the Frank–Starling mechanism (1). However, the two heat training groups experience a reduced PV compared with CON-1. Thus, in the present study, BV responses were similar between CHAMBER, SUIT, and CON-1 with an association of negative changes in the two heat training groups compared with CON-1, which may have had a relative negative effect on $\dot{V}O_{2max}$.

In accordance with our previous work (4), there were no group differences in changes in submaximal blood [La^{-}] and GE in fresh state (see Fig. 2 for explanation of fresh state). The lack of an effect of heat exercise training on GE in the fresh state is also in accordance with other heat exercise training or postexercise sauna studies lasting 3–5 wk performed on trained athletes (33). However, in the semifatigued state, SUIT had a greater improvement in GE than CON-1, with the average differences between CHAMBER and CON-1 also favoring heat training. These results are in line with our previous study (4). In agreement with greater improvement in Hb$_{mass}$ and GE in semifatigued state, SUIT led to greater increases in power output at 4 mmol·L^{-1} [La^{-}] compared with CON-1 (3.6% vs −0.6%, respectively), with CHAMBER being associated with a nonsignificant but, on average, larger increase (1.4%). In line with the present trend, 3 wk with heat stimulus in cyclists and runners induced favorable increases in work rates at 4 mmol·L^{-1} [La^{-}] compared with the control groups (33). Overall, given the observed benefits of heat training for power output at lactate threshold and given the predicative role of this variable for performance in endurance events (34), such training may represent a valuable addition to the habitual training routines of elite athletes.

Heat training and endurance performance. W_{max} is a good indicator of cycling performance (35), and based on the trend toward advantageous adaptations in submaximal exercise variables and $\dot{V}O_{2max}$ in both CHAMBER and SUIT, it was expected that these would both increase W_{max} from PRE to MID. However, only SUIT (~8%) induced a statistically significant larger increase in W_{max} than CON-1 (~2%), whereas CHAMBER did not (~4%). This is somehow contradictory to previous prolonged heat training studies, where no improvement in W_{max} has been observed (4,8). SUIT did also achieve a larger increase in W_{max} than CHAMBER. For the main performance test, 15-min power, the results mimics those of W_{max} indicating a small trend toward advantage of SUIT versus CHAMBER. The latter manifests also to the overall performance index (composed of power at 4 mmol·L^{-1} [La^{-}], W_{max}, and 15-min power). Because SUIT and CHAMBER had similar changes in Hb_{mass}, this is likely not the explanation to the small performance benefits in SUIT. One of the few differences between SUIT and CHAMBER during the intervention period was a lower room air temperature and lower RH in SUIT, which have been shown to affect thermal sensation (36). However, the differences in air temperature and RH are likely not very relevant, because this has minor or no impact on the microenvironment within the heat suit. The heat suit limits sweat evaporation with a theoretically higher skin temperature than heat chamber exercise. Increasing skin temperature can acutely reduce $\dot{V}O_{2max}$, increase the relative exercise intensity, and induce faster fatigue despite only modest increases in core temperature (15,16). The latter might contribute to explain why SUIT had a higher thermal sensation during the heat training and also indicate a possibly higher exercise stimulus during the heat sessions than CHAMBER, and theoretically contribute to explain some of SUIT's larger improvement in the performance index compared with CHAMBER. However, a larger exercise stimulus in SUIT is contradicted by no group differences in HR, RPE, or sRPE during the heat training sessions. Another speculation for the advantage of SUIT is related to their slightly higher mean power output during the heat training sessions (to achieve the target rectal temperature). However, all power outputs during the heat training sessions in SUIT and CHAMBER remained within the low exercise intensity zone (~36% and ~31% of W_{max}, respectively). Importantly, there were no statistical significant differences between SUIT and CHAMBER in percentage change in 15-min power, and when the two groups are pooled into one heat training group, both W_{max} and the performance index display a significantly larger increase than CON-1. Therefore, the lack of difference between CHAMBER and CON-1 may simply be due to between subject variation. However, the importance of Hb_{mass} for performance is supported by the correlations between increased Hb_{mass} and improvement in endurance performance variables seen across groups.

In accordance with the larger increase in pooled performance index, other heat exercise (37) or postexercising sauna bathing studies (26,33) lasting ≥3 wk report improvements in measures of endurance performance. Our findings are also in agreement with a similar 5-wk intervention in elite cyclists where a nonsignificant group averages an advantage of ~7% improvement in 15-min power in the heat training group (4). In the latter study, there was also a positive correlation between increases in 15-min power and increases in Hb_{mass}, which resembles the present findings of positive correlation between the performance index and increases in Hb_{mass}, indicating that changes in Hb_{mass} are associated with the observed larger adaptations after heat exercise training. To the contrary, another prolonged study with a similar methodological approach to the present study on less trained cyclists reported no difference in endurance exercise capacity between a heat training group and a control group (8). The reason(s) for this discrepancy remains unknown but can be related to differences in fitness level, age, dehydration during heat sessions, and temperature during testing. Finally, because it is established that both normal endurance training, especially high-intensity aerobic training (38), and heavy strength training (39) can improve endurance performance, it is important to stress that there were no significant differences between the two heat training groups and CON-1 in training volume, intensity distribution, or amount of heavy strength training. Therefore, it seems likely that the observed changes are due to the heat training.

Three weeks of heat maintenance exercise training and Hb_{mass}. Immediately after the initial 5 wk of heat training, a 3-wk heat maintenance period was commenced wherein $SUIT_{main}$ induced a larger gain in Hb_{mass} than $HEAT_{stop}$ and a nonsignificant trend toward advantage compared with CON-2, whereas there was no difference between $HEAT_{stop}$ and CON-2. The continuation of rise in Hb_{mass} in $SUIT_{main}$ was somewhat surprising, as based on a previous case study where we observed that three weekly heat sessions could maintain an initial Hb_{mass} increase, but not substantially increase it (14). However, 3–4 weekly sessions of ~30 min postexercise sauna bathing has been shown to increase both exercise performance in temperate conditions (26,33) and RBCV (26) in trained runners, although the latter is not an universal finding (40). Under normal circumstances, red blood cells have a life expectancy of about 120 d. After high-altitude (9) exposure, RBCV is, however, rapidly restored to prealtitude conditions and is speculated to counteract an unnecessary high RBCV (41). In the present study, however, no such rapid restoration to prelevels was observed and perhaps questions the proposed rationale for neocytolysis to restore RBCV once a given stimulus is terminated. During the entire 8-wk heat training period in $HEAT_{main}$ and $HEAT_{stop}$, Hb_{mass} was increased by 5.7% (4.7%) and 4.0% (3.5%), respectively, whereas the number for CON-2 was 1.1% (1.9%) during this period. Arguably, this exceeds the benefits of high-altitude training, which may lead to ~1.1% increases in Hb_{mass} per 100 h (42), whereas other see no benefit (43,44), with $HEAT_{main}$ and $HEAT_{stop}$ having performed ~34 and ~25 heat training sessions each lasting 50 min, amounting to 28.5 and 21 h of heat exercise. Despite equivocal conclusions in the scientific literature (45), the present data indicate that long-term heat endurance training stands out as an efficient alternative to altitude training if the aim is to increase Hb_{mass}.

As with most studies, the present study is not without limitations. The testing was performed by assessors that were not blinded to allocation. However, the participants were elite cyclists experienced with the test battery and not likely to be majorly impacted by the test leader. Despite no significant group differences in training volume in the different intensity zones, there were average differences between groups. Although the authors have no reason to believe this impacted the results, this is not known. The present study did not measure skin temperature and did also not assess potential mechanisms behind the observed hematological adaptations. Performance was not measured after the maintenance phase, so despite maintenance of Hb_{mass}, it is not known if this translates into a maintenance of performance gains.

CONCLUSIONS

In conclusion, the present study demonstrates that 1) SUIT induces similar acute heat stimulus as CHAMBER, 2) both SUIT and CHAMBER increase Hb_{mass} after 5 wk of heat training compared with CON-1, 3) pooling SUIT and CHAMBER data elucidates that heat training induces a larger increase in performance index than CON-1, and 4) three weekly heat suit sessions performed for a total of 3 wk and in direct continuation of the initial 5-wk intervention induce a further increase in Hb_{mass} compared with $HEAT_{stop}$, whereas in this period, there were no differences between CON-2 and $HEAT_{stop}$ and no reduction in Hb_{mass} in $HEAT_{stop}$.

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The results of the present study do not constitute endorsement by the American College of Sports Medicine. The authors declare that the results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

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