International Journal of Sports Physiology and Performance, 2018, 13, 816-823
https://doi.org/10.1123/ijspp.2017-0007

Human Kinetics
ORIGINAL INVESTIGATION

Optimizing Heat Acclimation for Endurance Athletes: High- Versus Low-Intensity Training

Cyril Schmit, Rob Duffield, Christophe Hausswirth, Jeanick Brisswalter, and Yann Le Meur

Purpose: To determine the effect of high- versus low-intensity training in the heat and ensuing taper period in the heat on endurance performance. ***Methods:*** In total, 19 well-trained triathletes undertook 5 days of normal training and a 1-wk taper including either low- (heat acclimation [HA-L], n = 10) or high-intensity (HA-H, n = 9) training sessions in the heat (30°C, 50% relative humidity). A control group (n = 10) reproduced their usual training in thermoneutral conditions. Indoor 20-km cycling time trials (35°C, 50% relative humidity) were performed before (Pre) and after the main heat exposure (Mid) and after the taper (Post). ***Results:*** Power output remained stable in the control group from Pre to Mid (effect size: –0.10 [0.26]) and increased from Mid to Post (0.18 [0.22]). The HA-L group demonstrated a progressive increase in performance from Pre to Mid (0.62 [0.33]) and from Mid to Post (0.53 [0.30]), alongside typical physiological signs of HA (reduced core temperature and heart rate and increased body-mass loss). While the HA-H group presented similar adaptations, increased perceived fatigue and decreased performance at Mid (–0.35 [0.26]) were evidenced and reversed at Post (0.50 [0.20]). No difference in power output was reported at Post between the HA-H and control groups. ***Conclusion:*** HA-H can quickly induce functional overreaching in nonacclimatized endurance athletes. As it was associated with a weak subsequent performance supercompensation, coaches and athletes should pay particular attention to training monitoring during a final preparation in the heat and reduce training intensity when early signs of functional overreaching are identified.

Keywords: training camp, pacing, overreaching, training load, endurance performance

Heat acclimation (HA) has the capability to improve performance in the heat, potentially countering heat-induced performance decrements.[1] In general, HA is accomplished via regular exercise at submaximal intensities in environments of sufficient temperature.[2,3] In addition, due to the seemingly dose–response relationship of HA, current evidence suggests that greater than 15 days of HA to best improve performance in the heat.[4] Although current HA models, including long acclimation protocol (ie, >15 d) of low–moderate intensities (ie, 50% $\dot{V}O_2max$), are purported to optimize HA,[3] they are not representative of the ecological training program of endurance athletes.[5] More specifically, low-intensity HA protocols contrast with the combination of low- and high-intensity training and ensuing taper period often used prior to competition. Therefore, HA protocols fitting the dual requirements of providing HA while conforming to ecological training needs of endurance athletes remain to be investigated.

The perspective that high-intensity training in the heat offers a more appropriate training stimulus than low-intensity HA for well-trained endurance athletes has recently been proposed.[3] However, only 2 studies to date have investigated adaptations following HA protocols involving distinct exercise intensities. Following 7 days of exercising at a low (50% of the maximal oxygen consumption [$\dot{V}O_2max$] for 60 $min \cdot d^{-1}$) or a moderateintensity (75% of $\dot{V}O_2max$ for 30–35 $min \cdot d^{-1}$), Houmard et al[6] reported similar reductions in heart rate (HR), core temperature (T_{core}), and caloric expenditure of exercise, though performance outcomes were not reported. More recently, Wingfield et al[7] noticed larger decreases in HR and T_{core} and greater performance benefits (–5.9% [7.0%] vs –0.18% [3.9%] in a 20-km time-trial [TT] duration, at ~33°C, ~60% relative humidity [RH]) following a 5-day low- (cycling at 40% of peak power output [PO] for 90 min) versus moderate-intensity (30 min of alternating 40%–70% of peak PO) HA protocol. However, the "high-intensity" exercises used in these protocols were substantially lower than the typical high-intensity training sessions undertaken by endurance athletes.[8] Moreover, the lack of a control group for training volume and the lack of sufficient daily heat exposure in the high-intensity group (ie, <60 min)[3,9] clouded the interpretation of these results. On the one hand, this is regrettable because high-intensity training during HA could compensate for the fact that endurance athletes behave as already partially heat-acclimatized individuals,[2] which makes them prone to insufficient thermal impulse during typical submaximal HA. Conversely, training at high intensities in the heat is also likely to increase the internal training load and to augment the risk of functional overreaching (F-OR). As F-OR has been associated with altered cardiac function[10] and impaired perceptual responses to exercise,[11] these maladaptations are likely to counteract the positive effects of HA on endurance performance. To our knowledge, no performance impairment in the heat has been reported following HA; however, athlete's tolerance to the training regimen remains a crucial concern, especially when a training camp in the heat is scheduled before a major competition.

Endurance athletes' precompetitive programs typically include a taper phase between the overload phase (eg, training camp in the heat) and the competition to reduce physiological and psychological stress of daily training and optimize sport performance.[12] This issue appears of further relevance when high-intensity training is scheduled in the heat due to the associated

Schmit and Le Meur are with the Laboratory of Sport, Expertise and Performance (EA 7370), Research Dept, French National Inst of Sport, Expertise and Performance (INSEP), Paris, France. Duffield is with the Sport & Exercise Discipline Group, Faculty of Health, University of Technology Sydney (UTS), Moore Park, Australia. Hausswirth, Brisswalter, and Le Meur are with LAMHESS, University of Côte d'Azur, Nice, France. Le Meur is also with AS Monaco Football Club, Monaco. Schmit (cyril.schmit@gmail.com) is corresponding author.

increased internal training load. However, the performance supercompensation occurring during the taper phase when combined with heat exposure has not been described in the context of HA programs. Within this framework, the present study investigated the respective effects of either high- (HA-H) or low-intensity (HA-L) training sessions in the heat on self-paced endurance performance in well-trained athletes before and after a 1-week taper period.

Methods

Participants

A total of 29 well-trained male triathletes (age = 32 [4] y, body mass = 70.3 [6.1] kg, and $\dot{V}O_2max = 62.1[5.4] mL \cdot kg^{-1} \cdot min^{-1}$) volunteered to participate in this study.[13] All participants had no heat exposure in the previous 3 months. The experimental design of the study was approved by the ethics committee of Hôtel Dieu, Paris (acceptance n°2015-A01220-49) and was performed in accordance with the Declaration of Helsinki.

Experimental Design

The participants were randomly ascribed to the control, HA-L, or HA-H groups according to a matched group experimental design based on performance level and habitual training load (Table 1).

The 4 phases of the experimental protocol are presented in Figure 1. Phase I consisted of 2 weeks of each participant's own "usual" training regimen and served as a basis for phases II and III (ie, matched for weekly training distribution, activities, and content). During phase III (1 wk), 1 group of participants continued its usual training program in temperate conditions (control, n = 10), whereas 2 groups undertook respective HA procedures either in the form of low- (HA-L, n = 10) or high-intensity (HA-H, n = 9) training sessions. All participants then completed a final 1-week taper (phase IV) during which their normal training load was decreased by 50% according to the recommendations provided by Bosquet et al.[12]

All participants completed four 20-km TTs in hot conditions (35°C, 50% RH; Thermo Training Room®, Paris, France): 1 familiarization test during phase I and 3 others at the end of phases II (Pre), III (Mid), and IV (Post). Each test was systematically completed at the same hour of the same day for each participant.

Training Monitoring

Participants were instructed to report a session rating of perceived exertion[14] immediately after each session in an individual standardized logbook. This made it possible to quantify individual training load, as defined as the volume multiplied by the rating of perceived exertion for the training session.[15]

Heat-Acclimatization Procedure

No variable except the intensity of training sessions performed in the heat differed between the 2 HA groups during phases III and IV (ie, same ambient conditions, heat exposure duration, time of the day). Specifically, over phase III, each participant of the HA-L group reproduced 1 hour per day during 5 consecutive days of the lowest intensity sessions of his personal training week at 30°C and 50% RH (eg, 60 min of an initial 90-min running session at 11 km·h^{-1}), whereas athletes from the HA-H group underwent 1 hour per day of their personal highest intensity sessions in similar conditions (eg, 8 repetitions of 400 m at 19 km·h^{-1}, with warm-up and recovery phases). A similar split between training duration in temperate and hot conditions was maintained and adjusted for the tapering phase (ie, 30 min of training in the heat and the remaining training duration performed out of the heat chamber). When the training sessions exceeded 60 minutes (for phase III) and 30 minutes (for phase IV), training in the heat was performed first (ie, before the remaining training in temperate conditions) in order to limit the differences in starting T_{core}. Any session of prolonged training duration (or >60 min) involving a range of training intensities was structured so that only the high- (for HA-H) or low-intensity (for HA-L) parts of the session were performed in the heat. Consequently, this allowed heat exposure during the appropriate exercise intensity range, without altering overall training volume or intensity. For each participant, the selection of the training sessions performed in the heat was prescribed according to their typical training week in phase I and relative to session's absolute intensity (in km·h^{-1} or W) and duration (≥60 min). These protocols were designed in accordance with recent meta-analyses, which have reported that thermal environments ≥30°C are effective to induce HA, although highlighting that sufficient daily heat exposure is recommended (ie, ≥60 min).[3,9]

During phases III and IV, outdoor environmental conditions from 6:00 AM to 10:00 PM were 6.5°C (4.1°C) and 65.0% (15.3%) RH. To minimize intervention-based management differences between groups during these 2 weeks, participants of the control group undertook some training sessions in the lab (at 21°C, 50% RH).

TT Protocol

The TT protocol is presented in Figure 1. Participants were required to avoid heavy training or fatiguing activities during the 24 hours prior to each laboratory session. The protocol was performed on participants' own bike mounted on a Cyclus2 ergometer (RBM GmbH, Leipzig, Germany). To control for fluid intake between sessions, the participants were instructed during the second familiarization that they could drink *ad libitum* during the warm-up and TT, with the volume of water ingested measured, and then replicated for the ensuing experimental sessions. During the warm-up and the TT, convective airflow from a fan was used to mimic field conditions (750 mm, ~6 m·s^{-1} and ~8.5 m·s^{-1}, respectively). No feedback was provided to the participants during TTs except for the distance remaining. Pacing analysis was performed over a 5-km-block basis, as it appears effective in discriminating heat-related alterations in pacing strategies during a series of 20-km TTs.[16]

Experimental Measurements

Six and a half hours before arriving at the laboratory,[17] the participants were instructed to swallow an ingestible radio telemetry capsule to measure T_{core} via an external precalibrated sensor (BodyCap, Caen, France). The participants were also instructed to consume 1 L of water in the 2 hours prior to visiting the laboratory. Upon arrival at the laboratory, the participants completed a 100-mm visual analogic scale to quantify their level of perceived fatigue. Before and immediately after the warm-up and the TT, towel-dried nude body mass was measured using a digital platform scale (ED3300; Sauter Multi-Range, Balingen, Germany) to estimate sweat loss (pre–post body mass + fluid ingested). During the TT, participant's rating of perceived exertion was assessed every

Table 1 Mean Individual Characteristics and Data From Training Monitoring for Each Group During the Experimental Protocol

	Phase II			Phase III			Phase IV		
Variable	C	HA-L	HA-H	C	HA-L	HA-H	C	HA-L	HA-H
Control and training data									
No of swimming, cycling, and running sessions	3/3/3	3/3/3	3/3/3	3/3/3	3/3/3	3/3/3	3/3/3	3/3/3	3/3/3
TV, min									
Temperate	744 (105)	772 (162)	698 (135)	738 (97)	472 (170)	401 (138)	384 (66)[a]	226 (91)[a]	210 (67)[a]
Heat	0 (0)	0 (0)	0 (0)	0 (0)	300 (0)	300 (0)	0 (0)	150 (0)[a]	150 (0)[a]
RPE, AU	12.5 (1.6)	12.3 (1.6)	12.4 (1.8)	12.3 (1.9)	13.3 (1.5)[a]	14.5 (2.0)[a,b]	11.8 (0.8)	11.9 (2.6)[a]	12.1 (3.6)[a]
TL, AU	9406 (2368)	9559 (2754)	8573 (1821)	9164 (2442)	10,240 (2606)[a]	9991 (2203)[a,b]	4561 (912)[a]	4414 (1208)[a,c]	4316 (1462)[a,c]
Fatigue, AU	37 (21)	46 (26)	46 (23)	36 (27)	48 (26)	62 (22)[a]	30 (15)	41 (21)	42 (32)[a]

Abbreviations: C, control; HA-H, heat acclimation at high exercise intensity; HA-L, heat acclimation at low exercise intensity; RPE, rating of perceived exertion; TL, training load; TV, training volume; AU, arbitrary units. Note: Results are presented as the group mean (SD).

[a]Changes at least *likely* compared with the previous week. [b]Differences in change from phase II at least *likely* compared with the HA-L group. [c]Differences in change from phase III at least *likely* compared with the control group.

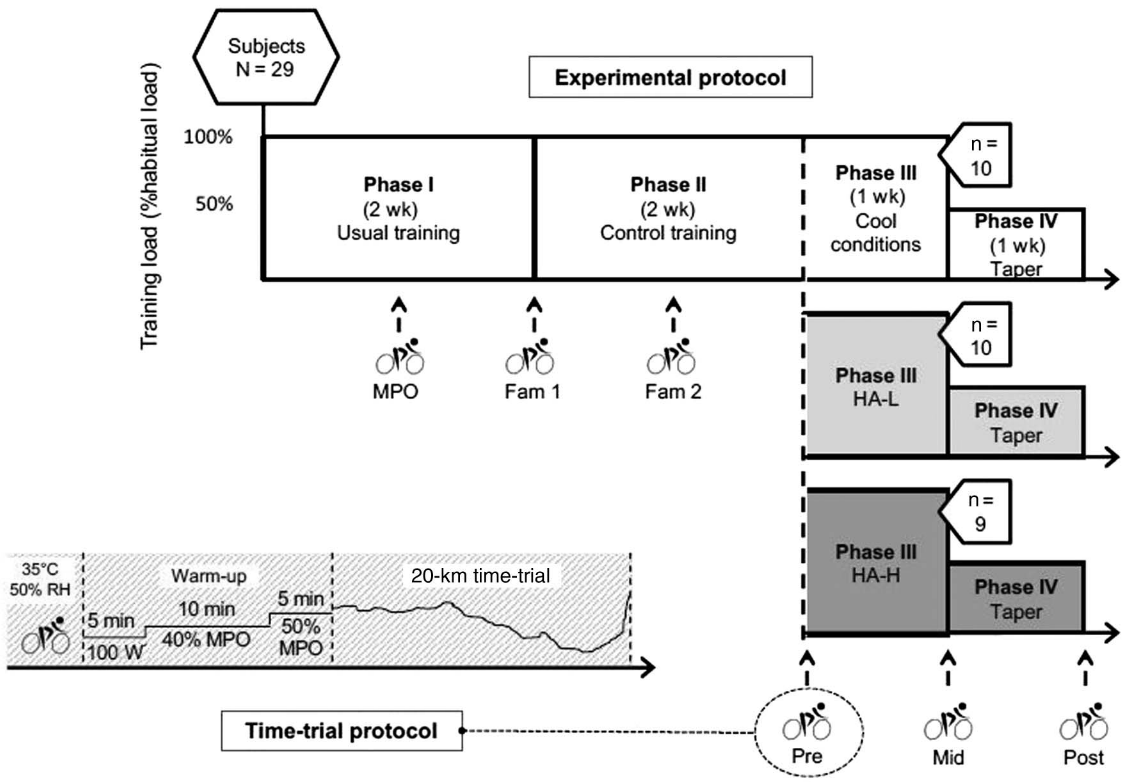

Figure 1 — Schematic representation of the experimental and time-trial protocols. MPO indicates maximal power output; Fam, familiarization session; HA-L, heat acclimation at low exercise intensity; HA-H, heat acclimation at high exercise intensity; RH, relative humidity.

5 km.[14] T_{core} values were recorded at the beginning and the end of the warm-up, and every 5 km during the TT. HR was continuously sampled every 5 seconds.

Statistical Analysis

Data were analyzed using a magnitude-based inference approach for all parameters.[18] All data were log transformed before analysis to reduce bias arising from nonuniformity of error. For clarity, the values presented in the text, tables, and figures are not transformed. The magnitude of the within-group changes, between-groups differences in the changes, and differences in the changes of group mean were interpreted by using values of 0.2, 0.6, 1.2, 2.0, and 4.0 of the variation as thresholds for small, moderate, large, very large, and extremely large differences in the change between the trials.[18] The smallest worthwhile change was defined as (1) $0.2 \times 1.3\%$ for TT's performance,[19] (2) $0.2 \times 1.3 \times 2.5\%$ for PO values,[20] and (3) a small standardized effect based on Cohen's effect size (ES) principle ($0.2 \times$ between-athletes SD[18]) for other parameters. Accordingly, the smallest worthwhile change was determined to be 0.3% in performance time and 0.7% in PO. Quantitative chances of higher or lower values than the smallest worthwhile change were evaluated qualitatively as follows: <1%, almost certainly not; 1% to 5%, very unlikely; 5% to 25%, unlikely; 25% to 75%, possible; 75% to 95%, likely; 95% to 99%, very likely; and >99%, almost certain. If the chance of higher or lower values was >5%, the true difference was assessed as *unclear*. Otherwise, we interpreted that change as the observed chance.[18] The practical interpretation of an effect was deemed *unclear* when the 90% confidence interval of standardized change/difference included zero.[18] All values are presented as mean (SD).

Results

Monitoring Data

Training Load. During phase III, the HA-L and HA-H groups showed likely small and almost certain moderate increases in training load (ES: 0.28 [0.13] and 0.73 [0.19], respectively), with a likely small between-groups difference in changes (0.35 [0.22]). During phase IV, all 3 groups displayed almost certain very large decreases in training load, with likely greater decreases in training load for the HA-L and HA-H groups compared with the control group (–0.65 [0.39] and –0.78 [0.63], respectively).

Perceived Fatigue. Within-group differences in fatigue scores showed a likely moderate increase after phase III for the HA-H group (0.61 [0.45]) but unclear changes for the control and HA-L groups (0.00 [0.45] and 0.14 [0.85], respectively). After the taper, the HA-H group displayed a likely moderate reduction in fatigue scores (–0.93 [1.03]) with fatigue level back to baseline values (unclear changes with phase II).

TT Data

Changes in average PO and TT duration from Pre to Post are shown in Figure 2. The temporal changes in PO for each TT are shown in Figure 3.

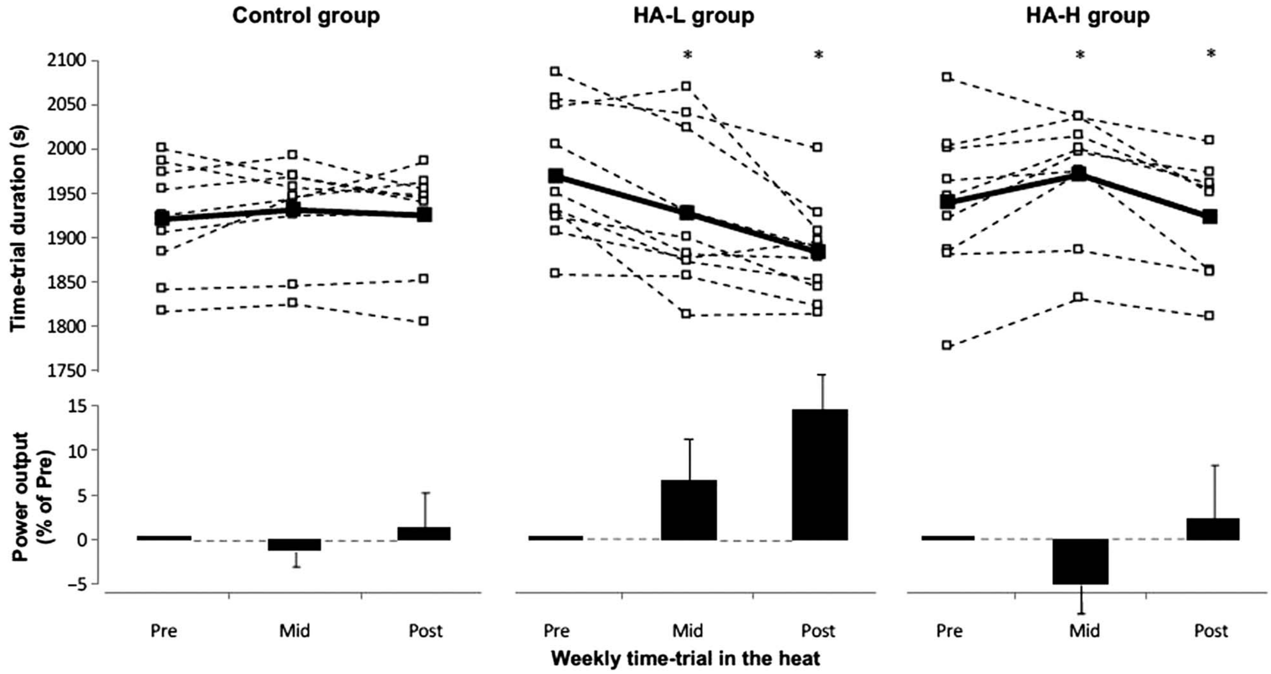

Figure 2 — Individual and average time-trial duration and corresponding relative changes in average power output for each group and for the 3 trials of the experimental protocol. The thick line represents the group average. HA-L indicates heat acclimation at low exercise intensity; HA-H, heat acclimation at high exercise intensity. *Changes at least *very likely* large from the precedent trial.

Average Power Output. Between-groups differences were unclear at baseline. From Pre to Mid, the control group displayed unclear changes in PO (–1.3% [1.8%]). In contrast, the HA-L group showed a very likely very large increase in PO (6.7% [4.6%]), whereas the HA-H group demonstrated a very likely large decrease in PO (–4.9% [3.5%]). The difference in PO at Mid between the HA-H and the HA-L groups was very likely very large (–8.2% [8.3%]).

From Mid to Post, all 3 groups displayed an increase in PO, which was likely small for the control group (1.8% [1.3%]), very likely large for the HA-L group (6.4% [3.9%], and very likely very large for the HA-H group (7.6% [3.1%]). These increases were very likely larger for the HA-L and HA-H groups compared with the control group with unclear differences against each other (1.1% [4.4%]).

From Pre to Post, the control and the HA-H groups demonstrated unclear within-group changes (1.3% [3.8%] and 2.3% [6.0%], respectively) and unclear between-groups difference in changes (1.6% [6.9%]) in PO, whereas the HA-L group showed an almost certain extremely large increase in PO (14.5% [4.4%]).

TT Duration. Between-groups differences were unclear at baseline (2.4% [2.8%]). From Pre to Mid, the control group displayed unclear changes in performance (–0.2% [1.5%]). In contrast, the HA-L group showed an almost certain large decrease in TT duration (–2.2% [1.1%]), whereas the HA-H group demonstrated a very likely large increase in TT duration (1.7% [1.3%]). From Mid to Post, decreases in TT duration were very likely large for the HA-L group (–2.3% [1.5%]), and almost certainly large for the HA-H group (–2.55 [1.0%]), with unclear between-groups differences in changes (0.3% [1.8%]). From Pre to Post, only the HA-L group showed a reduction in TT duration, which was almost certainly very large (–4.4% [1.3%]).

Heart Rate. Warm-up: both the HA-L and the HA-H groups showed possible small decreases in HR from Pre to Mid (ES: –0.24 [0.26] and –0.26 [0.16], respectively), with a possible small between-groups difference in change between these time points (0.20 [0.26]) (Table 2). The HA-H group also presented a possible small increase in HR values from Mid to Post (0.20 [0.11]).

TT: Within-group difference in maximal heart rate (HR_{max}) revealed a very likely small reduction in the HA-H group from Pre to Mid (ES: –0.43 [0.14]) and increases from Mid to Post both in the HA-H (0.72 [0.31]) and the HA-L (0.43 [0.63]) groups, with a possible small between-groups difference in changes (0.27 [0.39]).

Body-Mass Loss. At least possible small increases in the post-TT change in body mass loss were observed both for the HA-L and HA-H groups from Pre to Mid (ES, warm-up: HA-L, 0.51 [0.83]; HA-H, 0.51 [0.67] and TT: HA-L, 0.20 [0.23]; HA-H, 0.54 [0.26]) and from Mid to Post (warm-up: HA-L, 0.95 [0.69]; HA-H, 0.34 [0.57] and TT: HA-L, 0.24 [0.17]; HA-H, 0.20 [0.29]).

Core Temperature. Between-groups differences in T_{core} were systematically unclear upon arriving at each testing session. Within-group difference showed likely small reduction in T_{core} elevation from Mid to Post during the warm-up phases both for the HA-L and HA-H groups (ES: –0.50 [0.72] and –0.44 [0.70], respectively) with unclear between-groups difference in changes. For each group, unclear differences were found in T_{core} elevation between the TTs.

Discussion

This study investigated individualized high- or low-intensity HA training sessions during a 1-week pretaper period and a 1-week taper phase on endurance performance in the heat. The main finding was that the performance response was maximized in the HA-L protocol (ie, improvement after both the pretaper and

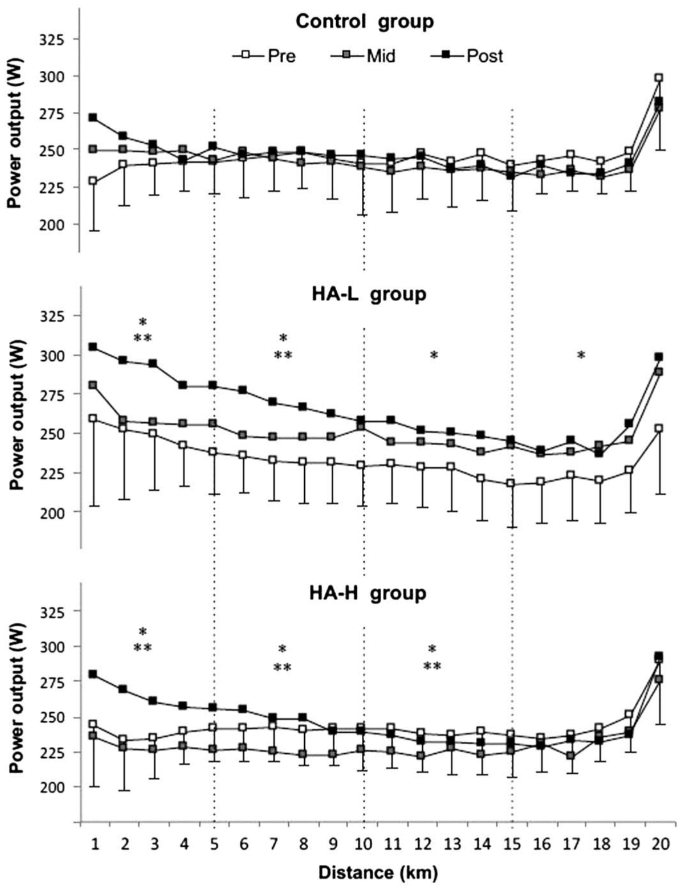

Figure 3 — Power output per kilometer for each group and for the 3 time trials in the heat. Results are presented as the group mean (SD). For clarity, only within-group differences in PO per 5-km split across the protocol are highlighted in the figure. Between-groups differences in changes and within-trial changes are presented in the "TT Data" subsection under "Results." Also, only error bars of Pre are presented, as errors bars of Mid and Post were within the same range. HA-L indicates heat acclimation at low exercise intensity; HA-H, heat acclimation at high exercise intensity. *Changes at least *likely* large between Pre and Mid. **Changes at least *likely* moderate between Mid and Post.

the taper phases), whereas the HA-H protocol resulted in a state of F-OR and a weak supercompensation after tapering despite similar physiological responses between respective HA protocols. Accordingly, the HA-induced benefits were seemingly counterbalanced by the F-OR-related maladaptations following high-intensity training in the heat, whereas the low-intensity HA protocol resulted in a positive performance response.

Heat Acclimation and Endurance Performance

A key outcome of any HA protocol is to ensure appropriate psychophysiological adaptations to the heat.[21] In the present study, physiological adaptations were comparable with expected HA-related changes in exercise responses. For example, small reductions in submaximal HR (possibly from plasma volume expansion) and T_{core} elevation (via enhanced blood flow distribution and evaporative cooling rate), and a small increase in body mass loss (possibly from earlier and increased sweat loss) following exercise.[22,23] Although these responses were not as evident as previous HA-related studies,[1–3] potentially due to the well-trained status and extent of heat exposure, they nonetheless represent the presence of HA.

Regardless of markers of HA, incongruent performance responses between the HA-L and HA-H groups were observed. Specifically, low-intensity training then tapering in the heat appeared ergogenic (cumulative gains in TT duration), which is coherent with the beneficial effects of both submaximal HA and tapering on endurance performance.[3,12] Of note, the magnitude of improvement at Mid (ie, after a 5-d HA) in the HA-L group was not as pronounced as that reported by Wingfield et al[7] (–2.2% [1.1%] vs –5.9% [7.1%]), possibly due to differences in heat exposure durations (60 vs 90 min·d^{-1}, respectively) and/or participants' fitness level (well-trained vs recreational participants, respectively). Furthermore, the fixed-intensity protocol used in the present study would elicit a diminishing (relative) daily heat strain, which may suggest that the large improvement noticed at Post existed due to taper-related benefits rather than heat-related physiological adjustments. For example, HR and body mass loss adaptations were evident from the end of phase III. However, the observation that T_{core} adaptations were only noted after phase IV also demonstrates heat-related implications in addition to taper-related benefits in performance changes at Post. A novel observation was the large increase in TT duration at Mid following HA-H. More precisely, the present study shows that high-intensity exercise as part of a HA protocol has the potential to impair performance in the heat to such an extent that it is not overcompensated following a 1-week taper phase and ultimately reaches the same performance level as a control group.

For the HA-L group, the corresponding increase in PO at Mid occurred with an up-regulated pacing strategy throughout the TT. The greater PO noticed during the second part of the TT is a well-known observation attributed to improved heat loss mechanisms[21–23]; however, the increased PO from TT start may speculatively relate to a higher confidence following HA. That is, experience is widely reported to be a powerful regulator of energy expenditure[24] and, relative to multiple training sessions in the heat, may provide participants with important cognitive strategies to optimize pacing. However, the progressive perceptual influence of heat exposures remains to be clarified as the control group did not report pacing improvement after 2 prior TT (Familiarization + Pre). By contrast, the HA-H group showed a ~5% decrease in PO at Mid, which was present throughout the TT until the endspurt, showing distinct similarities to the pacing alteration recently reported in subjects who temporarily were led to overreaching using a 6-day training overload.[25] In particular, 8 of the 9 current HA-H participants showed a performance decline. This propensity highlights a consistent harmful effect of an acute increase of the internal training load due to the combined nature of training intensity and environmental conditions. As such a homogenous response has not previously been reported in studies resulting in F-OR athletes,[26–28] this observation may provide scope for protocols differentiating internal versus external training load manipulation to investigate performance changes and optimize training programs. Consequently, despite the notion of HA-H potentially appearing more ecologically valid than HA-L for well-trained endurance athletes, it seems that high-intensity training in the heat is not beneficial to performance when it results in a state of F-OR.

Performance Response in HA-H: A Role for F-OR?

Given the limited literature on performance outcomes following HA-H, mechanistic explanations of the slower TT outcomes may

Table 2 Mean Physiological and Psychological Response to the Exercise Protocol

	Pre			Mid			Post		
Variables	**C**	**HA-L**	**HA-H**	**C**	**HA-L**	**HA-H**	**C**	**HA-L**	**HA-H**
Testing data									
HR, beats/min									
WU	113 (5)	119 (10)	115 (16)	114 (7)	117 (10)[a]	111 (12)[a,b]	112 (6)	118 (10)	114 (14)[a]
TT(mean)	162 (5)	167 (10)	159 (13)	163 (7)	167 (9)	158 (11)	164 (5)	173 (7)[a]	166 (10)[a,b]
TT(max)	180 (6)	179 (10)	179 (8)	179 (10)	181 (7)	175 (7)[a]	179 (8)	186 (8)[a]	182 (10)[a,b]
BML, kg									
WU	0.14 (0.24)	0.17 (0.22)	0.18 (0.15)	0.12 (0.24)	0.21 (0.25)[a]	0.28 (0.13)[a]	0.14 (0.26)	0.33 (0.25)[a]	0.33 (0.13)[a]
TT	0.72 (0.41)	0.81 (0.30)	0.71 (0.26)	0.75 (0.36)	0.87 (0.25)[a]	0.88 (0.19)[a,b]	0.73 (0.35)	0.97 (0.31)[a]	0.94 (0.27)[a]
T_{core}, °C									
Pre-WU	36.9 (0.4)	36.9 (0.3)	36.8 (0.3)	36.8 (0.3)	36.8 (0.3)	36.8 (0.4)	36.9 (0.2)	36.8 (0.3)	36.9 (0.3)
Post-WU	37.4 (0.2)	37.4 (0.3)	37.3 (0.2)	37.3 (0.3)	37.3 (0.3)	37.3 (0.3)	37.5 (0.3)	37.2 (0.3)[a]	37.3 (0.2)[a]
Post-TT	38.8 (0.5)	39.1 (0.3)	38.9 (0.7)	38.8 (0.6)	38.9 (0.4)	39.0 (0.4)	39.0 (0.5)	38.9 (0.5)	39.0 (0.4)
RPE, AU	16.8 (1.0)	17.1 (1.1)	17.3 (1.6)	17.0 (1.2)	17.2 (1.0)	17.7 (1.0)	17.0 (1.2)	17.4 (1.1)	17.7 (1.6)

Abbreviations: BML, body-mass loss; C, control; HA-H, heat acclimation at high exercise intensity; HA-L, heat acclimation at low exercise intensity; HR, heart rate; max, maximum; RPE, rating of perceived exertion; T_{core}, core temperature; TT, time trial; WU, warm-up; AU, arbitrary units. Note: Results are presented as the group mean (SD).
[a]Changes at least *possible* compared with the previous week (see the "Results" section for details). [b]*Possible* small difference in changes from the previous trial compared with the HA-L group.

borrow from F-OR literature. This may particularly be the case given the HA-H group concomitantly revealed typical signs of F-OR at Mid that dissipated during the taper phase. As context, gold standards for the diagnosis of F-OR athletes as recently defined,[28] include athlete's perception of an increased fatigue level and reduced performance level consecutive to an overload period. Both these symptoms were noticed in the present study only in the HA-H group, after phase III. The present results also showed that the HA-H protocol resulted in a moderate increase in internal training load during phase III associated with (1) an inability to reach the same HR_{max} value during the TT compared with Pre and (2) greater decreases in HR values during the warm-up compared with the HA-L group—a characteristic that eclipsed consecutive to the taper. Such reduced HR response at all exercise intensities has previously been evidenced in F-OR endurance athletes in response to intensified training periods.[10,11] Although T_{core} measures during HA exposure are not available, it could be speculated that the fixed higher-intensity training during HA-H alongside reduced cardiovascular function induced by F-OR symptoms may exacerbate the extent of training-induced hyperthermia. If so, this may explain the increased fatigue noted following HA-H, though the precise thermoregulatory responses during HA-H remain to be clarified. Regardless, given the ecological pertinence of the present study, undertaking high-intensity training in the heat may present a greater risk of F-OR symptoms similar to previous results reported in temperate conditions.[26]

Practical Applications

As HA-H resulted in a weaker performance supercompensation after a 1-week taper, the present results suggest that practitioners should be careful about the training programs used for heat-based training prior to competition. The present research suggests a role for training load monitoring in the heat, so that reduced workloads can be implemented if early signs of F-OR are identified. Of note, even if the HA-L protocol resulted in a better performance response than the HA-H one, the present results do not demonstrate that athletes should restrict to low-intensity training sessions in the heat to optimize HA. High-intensity training session may remain of interest after initial adaptations, that is, following 4 to 5 days of HA-L to maintain the thermal strain while the athletes are progressively acclimating to heat. Another option to maintain training intensity over a HA training camp could be to schedule high-intensity HA protocol including recovery days or low-intensity heat training after a high-intensity exercise session in temperate conditions.[29,30] A limit of the present study was that only one performance test was performed during taper making difficult the possibility to compare the amplitude of the performance rebound between groups. It cannot be excluded that the HA-H would have induced a greater performance rebound with an additional week of taper.

Conclusion

The present results show that both low- and high-intensity HA scheduled on the basis of athlete's usual training program are effective at inducing physiological HA. However, in contrast to the apparently systematic benefits of HA-L, HA-H does *not* represent an ergogenic intervention for endurance performance in the heat when it induces F-OR—even if a 1-week taper phase is programmed to dissipate the accumulated fatigue. In fact, such protocol applied to non-HA athletes may induce excessive fatigue and a subsequent weak performance supercompensation.

Acknowledgments

We receive funding for research on which this article is based from the French National Institute of Sport, Expertise and Performance (Paris). The authors report no conflict of interest and would like to thank Guillaume Renard for his support in driving the experimental part of the study.

References

1. Racinais S, Périard JD, Karlsen A, Nybo L. Effect of heat and heat acclimatization on cycling time trial performance and pacing. *Med Sci Sports Exerc*. 2015;47:601–606. doi:10.1249/MSS.0000000000000428
2. Taylor NA. Human heat adaptation. *Compr Physiol*. 2014;4:325–365. PubMed doi:10.1002/cphy.c130022
3. Tyler CJ, Reeve T, Hodges GJ, Cheung SS. The effects of heat adaptation on physiology, perception and exercise performance in the heat: a meta-analysis. *Sports Med*. 2016;46(11):1699–1724. PubMed doi:10.1007/s40279-016-0538-5
4. Guy JH, Deakin GB, Edwards AM, Miller CM, Pyne DB. Adaptation to hot environmental conditions: an exploration of the performance basis, procedures and future directions to optimise opportunities for elite athletes. *Sports Med*. 2015;45(3):303–311. PubMed doi:10.1007/s40279-014-0277-4
5. Issurin VB. New horizons for the methodology and physiology of training periodization. *Sports Med*. 2010;40(3), 189–206. PubMed doi:10.2165/11319770-000000000-00000
6. Houmard JA, Costill DL, Davis JA, Mitchell JB, Pascoe DD, Robergs RA. The influence of exercise intensity on heat acclimation in trained subjects. *Med Sci Sports Exerc*. 1990;22(5):615–620. doi:10.1249/00005768-199010000-00012
7. Wingfield GL, Gale R, Minett GM, Marino FE, Skein M. The effect of high versus low intensity heat acclimation on performance and neuromuscular responses. *J Therm Biol*. 2016;58:50–59. doi:10.1016/j.jtherbio.2016.02.006
8. Seiler S. What is best practice for training intensity and duration distribution in endurance athletes. *Int J Sports Physiol Perform*. 2010;5(3):276–291. doi:10.1123/ijspp.5.3.276
9. Chalmers S, Esterman A, Eston R, Bowering KJ, Norton K. Short-term heat acclimation training improves physical performance: a systematic review, and exploration of physiological adaptations and application for team sports. *Sports Med*. 2014;44(7):971–988. PubMed doi:10.1007/s40279-014-0178-6
10. Le Meur Y, Louis J, Aubry A, et al. Maximal exercise limitation in functionally overreached triathletes: role of cardiac adrenergic stimulation. *J Appl Physiol*. 2014;117(3):214–222. PubMed doi:10.1152/japplphysiol.00191.2014
11. Le Meur Y, Pichon A, Schaal K, et al. Evidence of parasympathetic hyperactivity in functionally overreached athletes. *Med Sci Sports Exerc*. 2013;45(11):2061–2071. PubMed doi:10.1249/MSS.0b013e3182980125
12. Bosquet L, Montpetit J, Arvisais D, Mujika I. Effects of tapering on performance: a meta-analysis. *Med Sci Sports Exerc*. 2007;39(8):1358–1365. doi:10.1249/mss.0b013e31806010e0
13. De Pauw K, Roelands B, Cheung SS, De Geus B, Rietjens G, Meeusen R. Guidelines to classify subject groups in sport-science research. *Int J Sports Physiol Perform*. 2013;8(2):111–122. doi:10.1123/ijspp.8.2.111
14. Borg G. *Borg's Perceived Exertion and Pain Scales*. Champaign, IL: Human Kinetics; 1998.
15. Foster C, Florhaug JA, Franklin J, et al. A new approach to monitoring exercise training. *J Strength Cond Res*. 2001;15(1):109–115. PubMed
16. Schmit C, Duffield R, Hausswirth C, Coutts AJ, Le Meur Y. Pacing adjustments associated with familiarization: heat versus temperate environments. *Int J Sports Physiol Perform*. 2016;11(7):855–860. doi:10.1123/ijspp.2015-0572
17. Lee JK, Nio AQ, Lim CL, Teo EY, Byrne C. Thermoregulation, pacing and fluid balance during mass participation distance running in a warm and humid environment. *Eur J Appl Physiol*. 2010;109(5):887–898. PubMed doi:10.1007/s00421-010-1405-y
18. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc*. 2009;41:3–13. PubMed doi:10.1249/MSS.0b013e31818cb278
19. Paton CD, Hopkins WG. Variations in performance of elite cyclists from race to race. *Eur J Sport Sci*. 2006;6(1):25–31. doi:10.1080/17461390500422796
20. Bonetti DL, Hopkins WS. Sea-level exercise performance following adaptation to hypoxia. *Sports Med*. 2009;39:107–127. PubMed doi:10.2165/00007256-200939020-00002
21. Périard JD, Racinais S, Sawka MN. Adaptations and mechanisms of human heat acclimation: applications for competitive athletes and sports. *Scand J Med Sci Sports*. 2015;25(S1):20–38. doi:10.1111/sms.12408
22. Nielsen B, Hales JR, Strange S, Christensen NJ, Warberg J, Saltin B. Human circulatory and thermoregulatory adaptations with heat acclimation and exercise in a hot, dry environment. *J Physiol*. 1993;460(1):467–485. doi:10.1113/jphysiol.1993.sp019482
23. Sawka MN, Leon LR, Montain SJ, Sonna LA. Integrated physiological mechanisms of exercise performance, adaptation, and maladaptation to heat stress. *Compr Physiol*. 2011;1:1883–1928. PubMed
24. Micklewright D, Papadopoulou E, Swart J, Noakes T. Previous experience influences pacing during 20-km time trial cycling. *Br J Sports Med*. 2010;44:952–960. PubMed doi:10.1136/bjsm.2009.057315
25. Skorski S, Hammes D, Schwindling S, et al. Effects of training-induced fatigue on pacing patterns in 40-km cycling time trials. *Med Sci Sports Exerc*. 2015;47(3), 593–600. doi:10.1249/MSS.0000000000000439
26. Aubry A, Hausswirth C, Louis J, Coutts AJ, Le Meur Y. Functional overreaching: the key to peak performance during the taper? *Med Sci Sports Exerc*. 2014;46(9):1769–1777. doi:10.1249/MSS.0000000000000301
27. Decroix L, Piacentini MF, Rietjens G, Meeusen R. Monitoring physical and cognitive overload during a training camp in professional female cyclists. *Int J Sports Physiol Perform*. 2016;1(7):933–939. doi:10.1123/ijspp.2015-0570
28. Meeusen R, Duclos M, Foster C, et al; European College of Sport Science; American College of Sports Medicine. Prevention, diagnosis, and treatment of the overtraining syndrome: joint consensus statement of the European College of Sport Science and the American College of Sports Medicine. *Med Sci Sports Exerc*. 2013;45(1):186–205. PubMed doi:10.1249/MSS.0b013e318279a10a
29. Scoon GS, Hopkins WG, Mayhew S, Cotter JD. Effect of post-exercise sauna bathing on the endurance performance of competitive male runners. *J Sci Med Sport*. 2007;10(4):259–262. PubMed doi:10.1016/j.jsams.2006.06.009
30. Stanley J, Halliday A, D'Auria S, Buchheit M, Leicht AS. Effect of sauna-based heat acclimation on plasma volume and heart rate variability. *Eur J Appl Physiol*. 2015;115(4):785–794. PubMed doi:10.1007/s00421-014-3060-1