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Human Kinetics
ORIGINAL INVESTIGATION

Postexercise Hot-Water Immersion Does Not Further Enhance Heat Adaptation or Performance in Endurance Athletes Training in a Hot Environment

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Purpose: Hot-water immersion (HWI) after training in temperate conditions has been shown to induce thermophysiological adaptations and improve endurance performance in the heat; however, the potential additive effects of HWI and training in hot outdoor conditions remain unknown. Therefore, this study aimed to determine the effect of repeated postexercise HWI in athletes training in a hot environment. ***Methods:*** A total of 13 (9 female) elite/preelite racewalkers completed a 15-day training program in outdoor heat (mean afternoon high temperature = 34.6°C). Athletes were divided into 2 matched groups that completed either HWI (40°C for 30–40 min) or seated rest in 21°C (CON), following 8 training sessions. Pre–post testing included a 30-minute fixed-intensity walk in heat, laboratory incremental walk to exhaustion, and 10,000-m outdoor time trial. ***Results:*** Training frequency and volume were similar between groups ($P = .54$). Core temperature was significantly higher during immersion in HWI (38.5 [0.3]) than CON (37.8°C [0.2°C]; $P < .001$). There were no differences between groups in resting or exercise rectal temperature or heart rate, skin temperature, sweat rate, or the speed at lactate threshold 2, maximal O_2 uptake, or 10,000-m performance ($P > .05$). There were significant ($P < .05$) pre–post differences for both groups in submaximal exercising heart rate (~11 beats·min^{-1}), sweat rate (0.34–0.55 L·h^{-1}) and thermal comfort (1.2–1.5 arbitrary units), and 10,000-m racewalking performance time (~3 min). ***Conclusions:*** Both groups demonstrated significant improvement in markers of heat adaptation and performance; however, the addition of HWI did not provide further enhancements. Improvements in adaptation appeared to be maximized by the training program in hot conditions.

Keywords: thermoregulation, heat stress, racewalking

A simple analysis of World Athletics Championships endurance running events revealed ~2% slower performance times in ambient temperatures >25°C compared with those in <25°C.[1] The negative effects of heat stress on endurance performance stem from the integration of several factors including cardiovascular strain,[2] increased reliance on muscle glycogen,[3] and unpleasant thermal perceptions.[4] Minimizing heat-mediated impairments in performance is a priority for many athletes, and racewalking athletes are particularly affected as the inefficiency of racewalking leads to a greater rate of heat gain compared with running at the same speed,[5] and the slower movement reduces evaporative and convective cooling capacity.[6] Data collected during the 2018 Commonwealth Games 20-km racewalking event demonstrated that these athletes reached peak core body temperatures of up to 41.2°C.[7] Hence, strategies are needed to optimize performance and reduce the risk of heat illness for racewalking athletes competing in the heat.

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The principal strategies for endurance athletes to minimize heat-mediated decrements in performance are heat acclimatization or acclimation (HA; ie, training in a natural or artificial hot/humid environment, respectively).[8] HA improves endurance performance in outdoor[9] and laboratory[10] environments, with a meta-analysis demonstrating a mean performance improvement of ~7% in endurance time-trial protocols across 27 studies.[11] The physiological adaptations underlying these improvements include lowered body temperatures, enhanced sweating and skin blood flow responses, plasma volume expansion, and cardiovascular stability.[1,9,10,12] Partial adaptation can occur in 4 to 5 days, but the magnitude and retention of HA is greater with protocols exceeding 8 days duration.[13] Despite the positive effects and efficiency of the adaptation process, only ~15% of athletes competing in a recent World Athletics Championships reported using a specific HA strategy in preparation for the event.[14] Several challenges have been documented in implementing HA, including limited access to heat chambers, the high cost of travel, as well as an increased training load and competing training priorities.[15] As a result, alternative forms of HA have been proposed.[16]

The use of passive heating (ie, hot-water immersion [HWI] and sauna bathing) has been investigated as an alternative strategy for heat adaptation in athletes, and its impact has recently been reviewed.[17] Sauna bathing (12 × 30-min exposures at 90°C) after exercise in temperate conditions increased running time to exhaustion by ~32%[18] and whole-body postexercise HWI (6 × 40 min exposures at 40°C) improved 5-km running performance time by ~5%.[19] A range of heat adaptations was also demonstrated following repeated postexercise HWI. As such, postexercise passive heating appears to be an effective HA strategy when training occurs in a temperate environment.

The combination and potential additive effect of training in hot outdoor conditions followed by passive heating have received little research attention. One study investigated training in the heat and passive heating on alternate days, which induced heat adaptation in both Paralympic and able-bodied triathletes.[20] However, it remains unclear if the supplementary passive heating contributed to the heat adaptation or if the adaptations were obtained exclusively from training in the heat. Therefore, the current study aimed to assess the effects of postexercise HWI on physiological markers of heat adaptation and endurance performance in athletes training in a hot environment. It was hypothesized that the addition of postexercise HWI would has beneficial effects on physiological markers of heat adaptation, including core body temperature, heart rate, plasma volume and sweat rate, and endurance performance.

Methods

Subjects

A total of 13 elite/preelite racewalking athletes participated, including 9 females (age = 25.4 [5.2] y, stature = 164.7 [3.9] cm, body mass = 52.7 [5.6] kg, sum of 7 skinfolds = 66 [17] mm, walking maximal O_2 uptake [VO_2max] = 55.5 [5.2] mL·kg·min^{-1}) and 4 males (age = 20.9 [6.2] y, stature = 179.6 [6.4] cm, body mass = 61.7 [5.0] kg, sum of 7 skinfolds = 35 [2] mm, walking VO_2max = 63.2 [2.8] mL·kg·min^{-1}). The sample included 7 elite athletes (World Athletics Championships and/or Olympic representatives) and 6 preelite athletes identified by their national federation as having future high-performance potential. The athletes were partially seasonally heat acclimatized as they were living and training outdoors during summer for 1 to 4 weeks prior. Ethical approval for this study was provided by the Australian Institute of Sport Human Research Ethics Committee in the spirit of the Declaration of Helsinki.

Design

The study design is illustrated in Figure 1. The athletes completed a racewalking training camp at the Australian Institute of Sport involving a 15-day training program outdoors during the southern hemisphere summer (mean afternoon high ambient temperature = 34.6°C). Within a control (CON) trial design, athletes were divided into 2 groups matched for racewalking VO_2max and 10,000-m performance time. The HWI group (n = 7 [3 elite and 4 preelite; 5 females], racewalking VO_2max = 58.1 [7.5] mL·kg·min^{-1}; 10,000-m time = 49.0 [2.7] min) completed postexercise HWI following an afternoon training session on 8 separate occasions. The CON group (n = 6 [4 elite and 2 preelite; 4 females], racewalking VO_2max = 57.5 [3.4] mL·kg·min^{-1}; 10,000-m time = 49.2 [3.3] min) completed the same training with immersion replaced by seated rest in a temperate environment (21°C, 50% relative humidity [RH]). The CON group was restricted from performing any recovery activities (eg, stretching, foam rolling) during the immersion period.

Pre–Post Testing

The athletes completed 3 days of testing both before and after the training program (Figure 1). All repeat testing took place in the same order and time of day for each individual. The athletes recorded their food and supplement intake for 24 hours prior to each initial testing day, which was replicated on the same days prior to repeat testing. Training was standardized on the day prior to testing, and no additional training was allowed on testing days. Athletes prepared

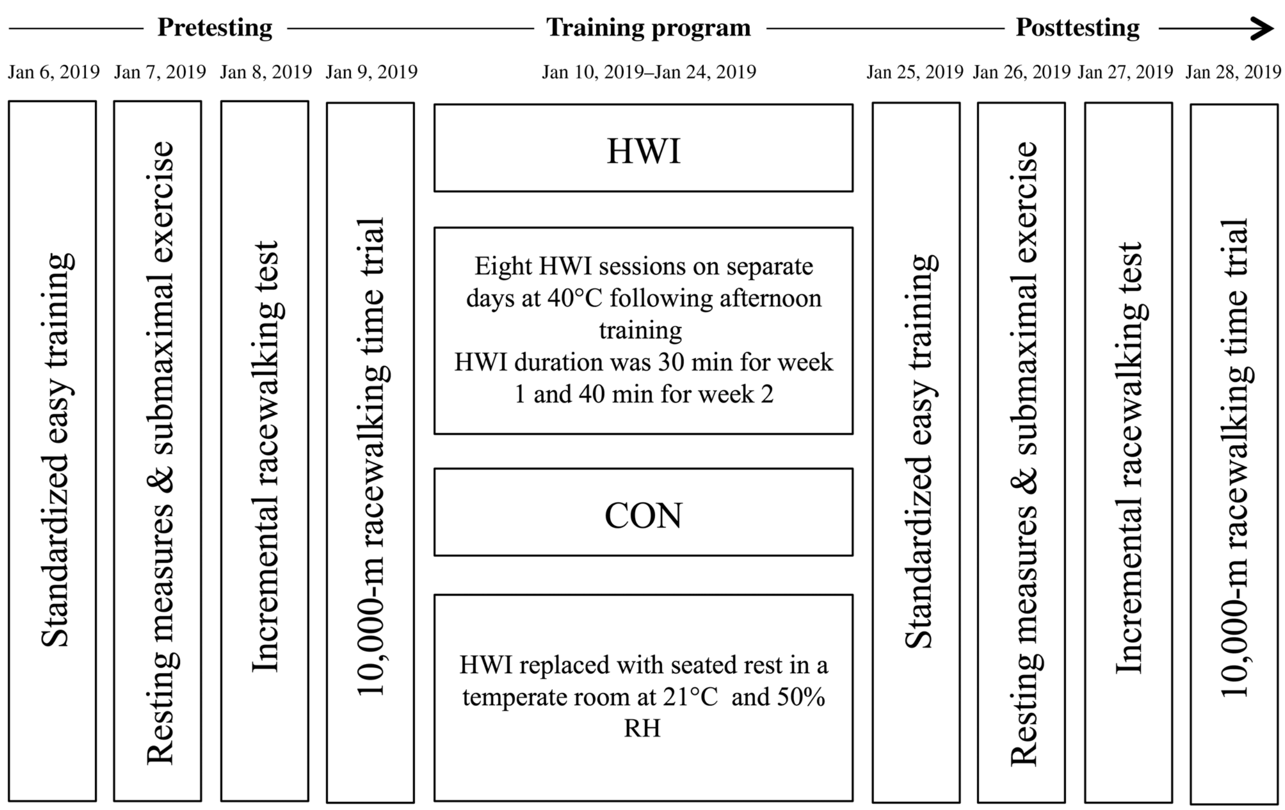

Figure 1 — Schematic of the experimental design. CON indicates control; HWI, hot-water immersion; RH, relative humidity.

for each test day like it was a high-priority event. Training attire and footwear were also standardized within individuals.

Resting Measures. Upon arrival, hydration status was determined from a midstream urine sample analyzed with a handheld refractometer (PAL-1-BLT/I; Atago, Tokyo, Japan) to confirm urine specific gravity was <1.020. If urine specific gravity was ≥1.020, 500 mL of water was consumed in a 20-minute period before continuing the procedures. After euhydrated status was confirmed, the athlete completed a 10-minute stabilization phase in the supine position with the eyes closed in an air-conditioned room (~22°C and 50% RH). Following this period, resting heart rate (heart rate monitor; Polar Electro Oy, Kempele, Finland), rectal temperature (T_{re}), and a venous blood sample (6 mL from an antecubital vein) were collected.

Blood samples were kept on ice before being centrifuged (1500 ×g for 10 min at 4°C) and analyzed by fluorescent flow cytometry (XN-L 550; Sysmex Corporation, Kobe, Japan) for hematocrit ratio and hemoglobin concentration, and plasma volume change was calculated.[21] Female samples were analyzed in a commercial laboratory for follicle-stimulating hormone, luteinizing hormone, oestradiol, progesterone, and prolactin, which allowed an ovarian hormone expert to estimate the menstrual cycle phase of each individual, together with an interview. The menstrual cycle phase could not be determined when the athlete was using a combined oral contraceptive pill (n = 4) or when the athlete was experiencing secondary amenorrhea (n = 1). Of the remaining female athletes, 3 were determined to be in the luteal phase and 1 in the follicular phase during pretesting, and 3 were determined to be in the follicular phase and 1 in the luteal phase during posttesting.

Submaximal 30-min Walk in Heat. Responses to heat stress were assessed by a 30-minute fixed-intensity treadmill walk (Trackmaster; Full Vision Inc, Newton, KS) in a heat chamber (COSMED T170 DE Med; h/p cosmos sports & medical gmbh, Nussdorf-Traunstein, Germany) maintained at 40°C and 40% RH. The test commenced after a 5-minute stabilization phase seated in the chamber. Treadmill speed was fixed at 80% of the athlete's current best 10-km racewalking speed (10.6 [0.5] km·h^{-1}), and a fan (8 km·h^{-1}) was used to simulate outdoor facing wind flow and evaporative cooling. A standardized volume (5 mL·kg^{-1}·mass^{-1}) of tepid water (18°C) was consumed during the walk.

Incremental Racewalking Test. An incremental racewalking test to exhaustion was performed on a custom-built treadmill as described previously.[22] Oxygen uptake was measured with a custom-built gas analyzer (Australian Institute of Sport) with VO_2max taken as the highest recorded value during the final stage. The lactate threshold 2 was defined as the walking speed at a capillary blood lactate concentration of 4 mmol (Lactate Pro 2; Arkray & Partners, United Square, Singapore) determined by Lactate-E (version 2.0).[23]

10,000-m Racewalking Performance. The athletes completed a 10,000-m racewalking time trial on an outdoor 400-m Mondo athletics track (Canberra, ACT, Australia) overseen by World Athletics officials. All athletes started at 9:00 AM and competed against each other. In accordance with World Athletics rules, the athletes had access to water and were aware of their elapsed distance and time.

Training Program

The training program was prescribed, delivered, and monitored by a level 5 Athletics Australia coach who has coached multiple racewalking athletes to Olympic medals. The training program was conducted outdoors and reflected the training of a high-performance racewalking athlete. All athletes completed the same training program; however, training distances were adjusted to suit individual training volume needs. The camp was designed for the purpose of HA in preparation for the 2019 World Athletics Championships and as such, the afternoon sessions commenced at 4:30 PM (Australian Eastern Daylight Time) when hot conditions were expected. Table 1 illustrates the program design and the environmental conditions of each session.

A validated wellness questionaire[24] was completed daily including perceived sleep quality (1 = very poor, 5 = very good); muscle soreness (1 = minimal, 10 = severe); fatigue (1 = not at all, 10 = very fatigued); general health (1 = poor, 10 = excellent); mood (1 = poor, 10 = excellent); physical readiness to train (1 = not at all, 10 = completely); and mental readiness to train (1 = not at all, 10 = completely).

Intervention Sessions

The athletes assigned to the HWI group completed HWI at 40.0°C(0.2°C) to the level of the sternum with submerged arms on 8 separate occasions (see Table 1) immediately[25] following afternoon training (mean [SD], training duration: 39.2 [4.8] min, training ambient temperature: 33.4°C [6.7°C], training RH: 34.4% [26.3%]). The HWI duration was 30 minute during the first week and 40 minute during the second week of training unless athletes were removed due to very hot thermal perception (ie, thermal sensation equal to 4) or symptoms of heat illness. The 40-minute duration was chosen to reflect the duration used in a previous study.[19] A shorter duration was implemented in the first week as the preceding training occurred in a hot environment as opposed to a temperate environment as per the previously mentioned previous study. The immersion was performed in the Australian Institute of Sport Recovery Center, which allowed the entire HWI group to perform immersion in the same pool simultaneously. In CON, the immersion was replaced with seated rest in an air-conditioned room (21°C, 50% RH) to allow a comparison to typical practice. No other HWI or hot baths were permitted during the camp and hot showers were kept to less than 10 minute.

Measurement and Instrumentation

Body Temperatures. The T_{re} was measured every 30 second using a telemetric capsule inserted one index finger length beyond the anal sphincter. This technique has greater agreement with core body temperature measured by rectal probe, compared with measurements of intestinal temperature measured by ingested capsule.[26] One system was used for the submaximal 30-minute walk test (e-Celsius Performance; BodyCap, Caen, France) and another for monitoring during the training program (VitalSense; Mini Mitter Co Inc, Bend, OR). Skin temperatures at the chest, arm, thigh, and leg were measured every 30 second during the submaximal 30-minute walk with iButtons (Maxim Integrated, San Jose, CA), and mean skin temperature was estimated using a weighted equation.[27]

Sweat Response. Changes in nude dry body mass using an electronic scale (FG-150KAL Platform scale; A&D Weighing, Seoul, Korea) were corrected for fluid ingestion to determine whole-body sweat rate during the submaximal 30-min walk test.

Perception. Rating of perceived exertion (6–20 category ratio scale where 6 = no exertion at all and 20 = maximal exertion),

Table 1 Training Program, Timing of Intervention Sessions, and Mean Environmental Conditions of Each Training Session

Time of Day	Jan 10, 2019	Jan 11, 2019	Jan 12, 2019	Jan 13, 2019	Jan 14, 2019	Jan 15, 2019	16 Jan, 2019
8:00 AM	Rest or easy training 19.2°C (0.5°C) 68.7% (0.6%) RH	Hills, 5–10 km 21.1°C (1.3°C) 73.3% (5.9%) RH	Long, 15–25 km 21.7°C (2.5°C) 71.0% (10.2%) RH	Rest or easy training 21.3°C (1.0°C) 39.3% (3.2%) RH	Easy, 8–10 km 20.7°C (0.6°C) 73.0% (3.6%) RH	Easy, 8–10 km 26.9°C (2.5°C) 49.5% (10.1%) RH	Long, 15–25 km 29.2°C (2.1°C) 37.6% (4.6%) RH
4:30 PM	Massage	Easy, 6 km 19.9°C (0.1°C) 87.5% (0.7%) RH HWI/CON	Easy, 6 km 33.6°C (0.4°C) 25.0% (1.4%) RH HWI/CON	Rest	Interval, 8 × 1.2 km 34.9°C (0.3°C) 29.7% (1.2%) RH	Easy, 6 km 39.4°C (0.1°C) 10.5% (0.7%) RH HWI/CON	Easy, 6 km 39.4°C (0.1°C) 10.0% (0.0%) RH HWI/CON
	Jan 17, 2019	**Jan 18, 2019**	**Jan 19, 2019**	**Jan 20, 2019**	**Jan 21, 2019**	**Jan 22, 2019**	**Jan 23, 2019**
8:00 AM	Rest or easy training 25.4°C (2.3°C) 42.7% (5.0%) RH	Hills, 5–10 km 24.4°C (1.5°C) 59.5% (10.0%) RH	Long, 15–25 km 24.4°C (1.2°C) 72.6% (7.4%) RH	Rest or easy training 18.2°C (0.4°C) 75.7% (0.6%) RH	Easy, 8–10 km 21.0°C (0.5°C) 70.7% (1.5%) RH	Easy, 8–10 km 23.8°C (2.0°C) 58.3% (6.9%) RH	Long, 15–25 km 25.9°C (1.9°C) 59.8% (6.3%) RH
4:30 PM	Massage	Easy, 6 km 39.4°C (0.2°C) 18.5% (0.7%) RH HWI/CON	Easy, 6 km 30.4°C (0.1°C) 49.5% (0.7%) RH HWI/CON	Rest	Interval, 8 × 1.5 km 31.9°C (0.5°C) 35.0% (2.6%) RH	Easy, 6 km 37.3°C (0.4°C) 20.0% (2.8%) RH HWI/CON	Easy, 6 km 28.3°C (0.4°C) 54.5% (3%) RH HWI/CON
	Jan 24, 2019						
8:00 AM	Rest or easy training 19.2°C (0.2°C) 77.0% (1.7%) RH						

Abbreviations: CON, control; HWI, hot-water immersion; RH, relative humidity.

thermal sensation (category ratio scale where −4 = very cold and 4 = very hot), and thermal comfort (category ratio scale where −4 very uncomfortable and 4 = very comfortable)[28] were recorded every 5 minute during the 30-minute submaximal walk test and HWI.

Environmental Conditions. Environmental conditions for the outdoor training sessions (Table 1) were obtained from the Australian Government Bureau of Meteorology (Canberra, station number: 70351, ~10 km from training location). The environmental conditions (wet-bulb globe temperature) for the outdoor time trials were measured with a portable heat stress meter (SD-2010; REED Instruments, Wilmington, NC) placed in direct sunlight 1 m above the walking surface. Wind speed was measured separately with an anemometer (5500 Weather Meter; Kestrel, Boothwyn, PA) parallel to the front straight of the athletics track.

Statistical Analysis

Visual inspection of residual plots did not reveal any obvious deviations from homoscedasticity or normality. Training program data were analyzed between groups via an independent samples *t* test. The pre–post testing data were analyzed both between groups (delta scores were calculated and analyzed via an independent samples *t* test) and within groups. (Absolute scores were compared via analysis of variance and paired samples *t* test.) Alpha was set at .05. For the self-reported wellness data, mean scores were analyzed across the entire training program (ie, 10th – 24th Jan) and separately, on the days immediately following the intervention sessions (ie, 12th, 13th, 16th, 17th, 19th, 20th, 23rd, 24th) to examine any global and acute effects on these measures, respectively. Results are reported as mean (SD).

Results

Training Program

There were no significant differences between groups for the mean training session frequency (23 [2] vs 22 [2] for HWI and CON; $P = .33$) or training distance completed (245 [34] vs 235 [45] km for HWI and CON; $P = .54$). When summing the duration of total heat exposure (ie, time spent in HWI and training in ambient conditions of >30°C), HWI were exposed to 660 minutes, and CON were exposed to 380 minutes of heat exposure. The self-reported athlete wellness data are illustrated in Table 2.

Intervention Sessions

During the intervention sessions, mean training duration (37.9 [4.0] vs 41.1 [2.3] min for HWI and CON; $P = .074$), mean training T_{re} (38.3°C [0.1°C] vs 38.2°C [0.1°C] for HWI and CON; $P = .5$), and peak training T_{re} (39.0°C [0.1°C] vs 38.9°C [0.1°C] for HWI and CON; $P = .4$) were similar between groups. However, the mean T_{re} during the immersion/rest period (38.5°C [0.3°C] vs 37.8°C [0.2°C] for HWI and CON; $P < .001$) and the T_{re} at the end of immersion/rest period (38.4°C [0.1°C] vs 37.5°C [0.1°C] for HWI and CON; $P < .001$) was significantly higher in HWI. The mean duration per session during immersion/rest at a $T_{re} > 38.5°C$ was significantly longer in HWI (18.1 [11.5] min) compared with CON (3.7 [2.0] min; $P < .001$). Only one athlete was removed from the immersion on 1 occasion (second exposure) 4 minute prior to achieving the prescribed duration due to high thermal discomfort (thermal comfort = +4).

Pre–Post Testing Between Groups

There were no between-group differences in delta scores for resting T_{re} (0.06°C [0.45°C] vs −0.05°C [0.40°C] for HWI and CON; $P = .66$), resting heart rate (−1 [8] beats per minutes [bpm] vs −1 [4] bpm; $P = .93$), or plasma volume expansion (4.7% [5.6%] vs 5.5% [4.4%] for HWI and CON; $P = .80$). The responses during the submaximal 30-minute walk tests are summarized in Table 3. The mean and individual responses to the incremental and 10,000-m racewalking tests are summarized in Figure 2.

Pre–Post Testing Within Groups

There were significant main effects for time ($P < .05$) and post hoc analyses demonstrated significant reductions during post testing in mean exercising heart rate in both HWI (162 [3] bpm vs 151 [13] bpm for pre and post; $P < .001$) and CON (172 [10] bpm vs 161 [8] bpm for pre and post; $P = .048$) and significant increases in sweat rate in both HWI (1.46 [0.40] $L \cdot h^{-1}$ vs 2.02 [0.49] $L \cdot h^{-1}$ for pre and post; $P < .001$) and CON (1.60 [0.28] $L \cdot h^{-1}$ vs 1.94 [0.23] $L \cdot h^{-1}$ for pre and post; $P = .03$). There were also significant improvements in thermal comfort during post testing in both HWI (−0.5 [0.6] vs 0.9 [0.9] for pre and post; $P = .004$) and CON (−0.1 [1.1] arbitrary units vs 1.1 [0.4] arbitrary units for pre and post; $P = .01$). Furthermore, the performance time became significantly faster during post testing in both HWI (49.0 [2.7] vs 46.5 [2.1] min for pre and post; $P = .003$) and CON (49.2 [3.3] vs 46.2 [2.3] min

Table 2 Summary of the Self-Reported Wellness Data Across the Program With Comparisons Between Groups

	Total program			Days following intervention sessions		
Variable	HWI	CON	P	HWI	CON	P
Sleep quality (1 = very poor, 5 = very good)	3.5 (0.4)	3.3 (0.4)	.329	3.6 (0.5)	3.4 (0.5)	.418
Muscle soreness (1 = minimal, 10 = severe)	3.7 (0.9)	5.0 (1.8)	.106	3.6 (1.2)	5.2 (1.9)	.084
Fatigue (1 = not at all, 10 = very fatigued)	4.4 (1.5)	5.9 (1.5)	.110	4.5 (1.5)	6.1 (1.7)	.089
General health (1 = poor, 10 = excellent)	8.5 (0.5)	7.6 (0.8)	.037*	8.6 (0.5)	7.6 (0.9)	.027*
Mood (1 = poor, 10 = excellent)	8.4 (0.7)	6.8 (1.0)	.007*	8.5 (0.7)	6.8 (1.0)	.006*
Physical readiness (1 = not at all, 10 = completely)	6.3 (0.8)	5.9 (0.9)	.460	6.0 (0.8)	6.0 (1.0)	.949
Mental readiness (1 = not at all, 10 = completely)	7.1 (0.7)	6.0 (1.0)	.032*	6.8 (1.0)	5.8 (1.1)	.097

Abbreviations: CON, control; HWI, hot-water immersion. Note: Data are represented as mean (SD).
*Significantly different between groups.

Table 3 Mean Absolute and Delta Scores (Post–Pre) for the Physiological and Perceptual Responses to the Submaximal 30-min Walk in the Heat for the HWI and CON Groups

	HWI			CON		
Variable	**Pre**	**Post**	**Delta**	**Pre**	**Post**	**Delta**
Exercising T_{re}, °C	38.1 (0.3)	38.0 (0.2)	–0.1 (0.4)	38.1 (0.3)	38.1 (0.2)	0.0 (0.2)
Exercising T_{sk}, °C	36.8 (0.5)	36.4 (0.6)	–0.36 (0.63)	36.9 (0.5)	36.4 (0.4)	–0.48 (0.58)
Heart rate, bpm	162 (13)	151 (13)*	–11 (4)	172 (10)	161 (8)*	–11 (9)
Sweat rate, $L \cdot h^{-1}$	1.46 (0.40)	2.02 (0.49)*	0.55 (0.15)	1.60 (0.28)	1.94 (0.23)*	0.34 (0.28)
RPE, AU	12.4 (1.7)	11.5 (1.5)	–0.9 (0.7)	12.6 (1.4)	11.3 (1.9)	–1.3 (0.9)
Thermal sensation, AU	2.8 (0.4)	2.4 (0.6)	–0.4 (0.5)	2.6 (0.4)	2.3 (0.6)	–0.3 (0.4)
Thermal comfort, AU	–0.5 (0.6)	0.9 (0.9)*	1.5 (0.7)	–0.1 (1.1)	1.1 (0.4)*	1.2 (0.8)

Abbreviations: AU, arbitrary unit; bpm, beats per minute; RPE, rating of perceived exertion; T_{re}, rectal temperature; T_{sk}, mean skin temperature. Note: Data are represented as mean (SD).
*Significantly different to pre within condition, $P < .05$.

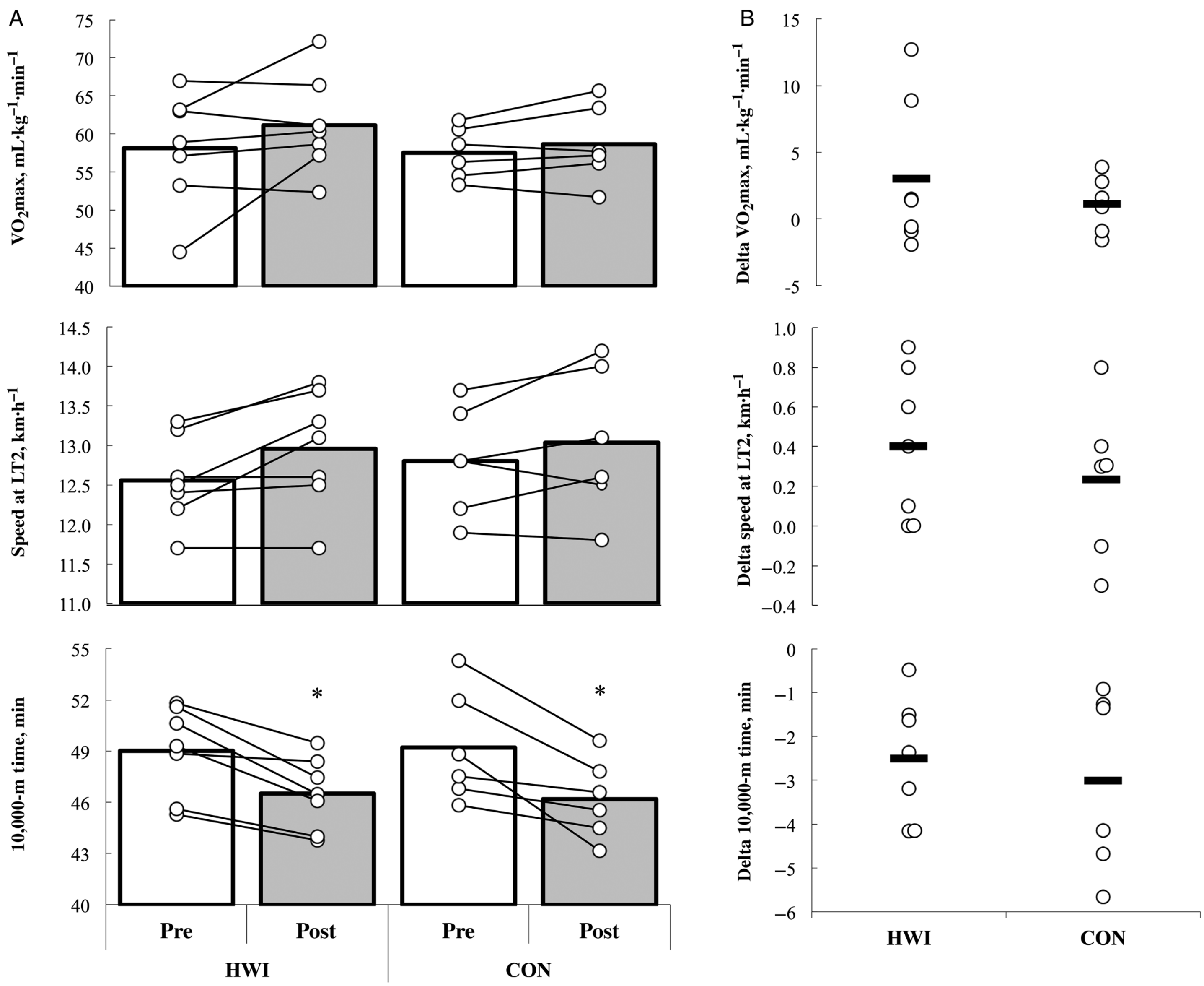

Figure 2 — (A) Absolute and (B) delta scores (post–pre) for race-walking VO_2max, walking speed at LT2 and 10,000-m performance time, pretraining, and posttraining program for the HWI and CON conditions. Data are presented as group means (columns and dashes) and individual responses (circles). CON indicates control; HWI, hot-water immersion; LT2, lactate threshold 2; VO_2max, maximal oxygen uptake. *Mean significantly different to PRE within condition.

for pre and post; $P = .02$). There were no other significant within-group differences for any other measure.

Environmental Conditions

For the 10,000-m performance tests, the pre and post ambient temperatures were 28.7°C (1.2°C) and 22.8°C (0.3°C), RH was 47.1% (3.5%) and 72.1% (1.2%), wet-bulb globe temperature was 24.4°C (0.4°C) and 20.5°C (0.2°C), and wind speeds were 1.5 (0.4) $m \cdot s^{-1}$ (with gusts up to 2.6 $m \cdot s^{-1}$) and 1.2 (0.3) $m \cdot s^{-1}$ (gusts up to 2 $m \cdot s^{-1}$).

Effect of Training Status

When the athletes were grouped according to training status (ie, elite or preelite), there was no significant difference in change in VO_2max ($P = .57$) or walking speed at lactate threshold 2 ($P = .52$) between groups.

Discussion

The current study aimed to assess the effects of postexercise HWI on physiological markers of heat adaptation and endurance performance in partially heat-acclimatized athletes training in a hot environment. The major finding was that the addition of HWI to a heat training program did not further enhance heat adaptation or performance in these elite/preelite endurance athletes, nor did it cause any impairment in performance. Both groups demonstrated significant improvement in markers of heat adaptation (ie, lowered heart rate, increased sweat rate, and improved thermal comfort during submaximal exercise in the heat; Table 3) and significant improvement in 10,000-m racewalking performance time for pre–post testing (Figure 2), and hence, the training that the athletes completed was effective without the additional HWI.

Large improvements in 10,000-m racewalking performance times were observed in both groups (~3 min), which may be explained by significant reductions in heart rate (11 bpm) and increases in sweat rate (0.34–0.55 $L \cdot h^{-1}$), as demonstrated in both groups during the 30-minute submaximal walk test. These responses reflect beneficial adaptations in cardiovascular function and thermoregulation.[1,11] It should also be highlighted that the post 10,000-m performance test was conducted in cooler conditions (22.8°C [0.3°C]) than the pretest (28.7°C [1.2°C]), which likely contributed to the large performance improvements recorded for both groups. The pretest could be classified as warm conditions while the posttest could be classified as temperate conditions.

The use of HWI has been investigated as a recovery strategy for athletes with equivocal results.[29] While the current study observed no significant improvements in perceived sleep quality, muscle soreness, fatigue, or training readiness globally across the camp, or on the days immediately following the HWI intervention sessions (Table 2), there were significantly higher self-reported scores for general health and mood in HWI participants compared with CON across the training program (Table 2). This result may be due to interindividual variability or a placebo effect; alternatively, there have been reports of improved health-related quality of life[30] and reduced depression rating[31] from sauna use, which also may apply to HWI.

The beneficial effects on performance demonstrated across both groups are likely due to a multitude of factors including a "training camp effect."[32] Specifically, the camp setting allowed the athletes to focus solely on their training and recovery with high levels of support from each other, as well as a team including an elite-level coach, massage therapist, sports scientists, and a chef who provided all meals. There is certainly some evidence that the hot weather also contributed to the performance enhancements with beneficial heat adaptations including increased sweat rate and improved thermal comfort[11]; however, without a CON group performing the same training in cool conditions, the precise effect of the heat training on adaptation and performance in the current study could not be quantified. A separate group training in cool conditions could not be incorporated into the current study as the athletes were performing a specific heat training camp in preparation for major events.

The timing of the HWI sessions in the current study may have contributed to failure of the HWI intervention to further enhance heat adaptation and performance. In the current study, the HWI intervention sessions were scheduled following afternoon training in the heat, during which the athletes were exposed to high whole-body temperatures. Although HWI extended the duration of the heat exposure, the extension may not have provided a strong enough stimulus to enhance the effects of having already trained in the heat. To address this issue, future research may investigate HWI following morning training sessions that occur in cooler conditions, and/or on rest days, to create additional opportunities for heat exposure. Others have suggested that HWI could be implemented within the taper to maintain heat exposure during periods of recovery prior to competition.[16]

While the training camp setting had high ecological validity, conducting most of the study outside of the laboratory created some limitations within the study design. Most importantly, the exercise intensity and environmental conditions could not be standardized across the program (and the 10,000-m performance tests); however, where possible, all other variables were controlled, in that athletes completed the same training sessions together simultaneously, on the same course and under the same environmental conditions. The authors should also highlight that the female participants were in different phases of their menstrual cycle from pretesting to posttesting, which may have affected the results as the T_{re} is elevated in the luteal phase and this elevation persists during exercise.[33] A strength of the study was that the athletes were partially seasonally heat acclimatized, which represents the heat acclimation status of many elite athletes who are preparing for hot competitions. (The current sample were training for the 2019 Doha World Athletics Championships.) By using athletes who are partially heat acclimatized, this research has greater relevance to such athletes. The authors do note, however, that the results of the current study may have been different for athletes who are not seasonally heat acclimated.

Practical Applications

1. The addition of postexercise HWI did not further enhance heat adaptation or performance in partially heat-acclimatized endurance athletes training in a hot environment.
2. Postexercise HWI did not impact perceived markers of sleep quality, muscle soreness, fatigue, or training readiness.
3. Significant heat adaptation and improvements in performance were evident for both groups, likely resulting from the training camp setting combined with the hot training environment.

Conclusions

After a 15-day heat training intervention, the authors observed significantly improved submaximal exercising heart rate, sweat rate, and thermal comfort, as well as improved 10,000-m racewalking performance in both groups. However, the addition of HWI did not further enhance heat adaptation or performance in partially heat-acclimatized athletes. Physiological adaptation appeared to be optimized from training in hot conditions.

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References

1. 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*. 2014;45(3):303–311. doi:10.1007/s40279-014-0277-4
2. Periard JD, Cramer MN, Chapman PG, Caillaud C, Thompson MW. Cardiovascular strain impairs prolonged self-paced exercise in the heat. *Exp Physiol*. 2011;96(2):134–144. PubMed ID: 20851861
3. Febbraio MA, Snow RJ, Stathis CG, Hargreaves M, Carey MF. Effect of heat stress on muscle energy metabolism during exercise. *J Appl Physiol*. 1994;77(6):2827–2831. PubMed ID: 7896628 doi:10.1152/jappl.1994.77.6.2827
4. Stevens CJ, Mauger AR, Hassmen P, Taylor L. Endurance performance is influenced by perceptions of pain and temperature: theory, applications and safety considerations. *Sports Med*. 2018;48(3):525–537. PubMed ID: 29270865 doi:10.1007/s40279-017-0852-6
5. Mora-Rodriguez R, Ortega JF, Hamouti N. In a hot-dry environment racewalking increases the risk of hyperthermia in comparison to when running at a similar velocity. *Eur J Appl Physiol*. 2011;111(6):1073–1080. PubMed ID: 21113615 doi:10.1007/s00421-010-1733-y
6. Saunders AG, Dugas JP, Tucker R, Lambert MI, Noakes TD. The effects of different air velocities on heat storage and body temperature in humans cycling in a hot, humid environment. *Acta Physiol Scand*. 2005;183(3):241–255. PubMed ID: 15743384 doi:10.1111/j.1365-201X.2004.01400.x
7. Stevens C, Ross M, Periard JD, Vallance B, Burke L. Core temperature responses to elite racewalking competition. *Int J Sports Physiol Perform*. 2020;15(6):892–895. doi:10.1123/ijspp.2019-0397
8. Racinais S, Alonso JM, Coutts AJ, et al. Consensus recommendations on training and competing in the heat. *Br J Sports Med*. 2015;49(18):1164–1173. PubMed ID: 26069301 doi:10.1136/bjsports-2015-094915
9. Racinais S, Periard JD, Karlsen A, Nybo L. Effect of heat and heat-acclimatization on cycling time-trial performance and pacing. *Med Sci Sports Exerc*. 2015;47(3):601–606. PubMed ID: 24977692 doi:10.1249/MSS.0000000000000428
10. Lorenzo S, Halliwill JR, Sawka MN, Minson CT. Heat acclimation improves exercise performance. *J Appl Physiol*. 2010;109(4):1140–1147. PubMed ID: 20724560 doi:10.1152/japplphysiol.00495.2010
11. 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 ID: 27106556 doi:10.1007/s40279-016-0538-5
12. Gerrett N, Kingma BRM, Sluijter R, Daanen HAM. Ambient conditions prior to Tokyo 2020 Olympic and Paralympic games: considerations for acclimation or acclimatization strategies. *Front Physiol*. 2019;10:414. PubMed ID: 31068829 doi:10.3389/fphys.2019.00414
13. Daanen HAM, Racinais S, Periard JD. Heat acclimation decay and re-induction: a systematic review and meta-analysis. *Sports Med*. 2018;48(2):409–430. PubMed ID: 29129022 doi:10.1007/s40279-017-0808-x
14. Périard JD, Racinais S, Timpka T, et al. Strategies and factors associated with preparing for competing in the heat: a cohort study at the 2015 IAAF World Athletics Championships. *Br J Sports Med*. 2017;51(4):264–270. PubMed ID: 27815238 doi:10.1136/bjsports-2016-096579
15. Casadio JR, Kilding AE, Cotter JD, Laursen PB. From lab to real world: heat acclimation considerations for elite athletes. *Sports Med*. 2017;47(8):1467–1476. PubMed ID: 28035584 doi:10.1007/s40279-016-0668-9
16. Saunders PU, Garvican-Lewis LA, Chapman RF, Periard JD. Special environments: altitude and heat. *Int J Sport Nutr Exerc Metab*. 2019;29(2):210–219. PubMed ID: 30676138 doi:10.1123/ijsnem.2018-0256
17. Heathcote S, Hassmen P, Zhou S, Stevens C. Passive heating: reviewing practical heat acclimation strategies for endurance athletes. *Front Physiol*. 2018;9(9):1851. doi:10.3389/fphys.2018.01851
18. 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 ID: 16877041 doi:10.1016/j.jsams.2006.06.009
19. Zurawlew MJ, Walsh NP, Fortes MB, Potter C. Post-exercise hot water immersion induces heat acclimation and improves endurance exercise performance in the heat. *Scand J Med Sci Sports*. 2016;26(7):745–754. PubMed ID: 26661992 doi:10.1111/sms.12638
20. Stephenson BT, Tolfrey K, Goosey-Tolfrey VL. Mixed active and passive, heart rate-controlled heat acclimation is effective for paralympic and able-bodied triathletes. *Front Physiol*. 2019;10:1214. PubMed ID: 31616314 doi:10.3389/fphys.2019.01214
21. Dill DB, Costill DL. Calculation of percentage changes in volumes of blood, plasma, and red cells in dehydration. *J Appl Physiol*. 1974;37(2):247–248. PubMed ID: 4850854 doi:10.1152/jappl.1974.37.2.247
22. Saunders PU, Telford RD, Pyne DB, et al. Improved running economy in elite runners after 20 days of simulated moderate-altitude exposure. *J Appl Physiol*. 2004;96(3):931–937. doi:10.1152/japplphysiol.00725.2003
23. Newell J, Higgins D, Madden N, et al. Software for calculating blood lactate endurance markers. *J Sports Sci*. 2007;25(12):1403–1409. PubMed ID: 17786693 doi:10.1080/02640410601128922
24. Nässi A, Ferrauti A, Meyer T, Pfeiffer M, Kellmann M. Development of two short measures for recovery and stress in sport. *Eur J Sport Sci*. 2017;17(7):894–903. doi:10.1080/17461391.2017.1318180
25. Heathcote S, Hassmen P, Zhou S, Taylor L, Stevens C. How does a delay between temperate running exercise and hot-water immersion alter the acute thermoregulatory response and heat-load? *Frontiers Physiol*. 2019;10:1381. doi:10.3389/fphys.2019.01381
26. Kenefick RW, Ely BR, Cheuvront SN, Palombo LJ, Goodman DA, Sawka MN. Prior heat stress: effect on subsequent 15-min time trial

performance in the heat. *Med Sci Sports Exerc*. 2009;41(6):1311–1316. PubMed ID: 19461533 doi:10.1249/MSS.0b013e3181988c14
27. Ramanathan NL. A new weighting system for mean surface temperature of the human body. *J Appl Physiol*. 1964;19(3):531–533. PubMed ID: 14173555 doi:10.1152/jappl.1964.19.3.531
28. Zhang H, Huizenga C, Arens E, Wang D. Thermal sensation and comfort in transient non-uniform thermal environments. *Eur J Appl Physiol*. 2004;92(6):728–733. PubMed ID: 15221406 doi:10.1007/s00421-004-1137-y
29. McGorm H, Roberts LA, Coombes JS, Peake JM. Turning up the heat: an evaluation of the evidence for heating to promote exercise recovery, muscle rehabilitation and adaptation. *Sports Med*. 2018;48(6):1311–1328. PubMed ID: 29470824 doi:10.1007/s40279-018-0876-6
30. Strandberg TE, Strandberg A, Pitkala K, Benetos A. Sauna bathing, health, and quality of life among octogenarian men: the Helsinki businessmen study. *Aging Clin Exp Res*. 2018;30(9):1053–1057. PubMed ID: 29188579 doi:10.1007/s40520-017-0855-z
31. Janssen CW, Lowry CA, Mehl MR, et al. Whole-body hyperthermia for the treatment of major depressive disorder: a randomized clinical trial. *JAMA Psychiatry*. 2016;73(8):789–795. PubMed ID: 27172277 doi:10.1001/jamapsychiatry.2016.1031
32. Turner G, Fudge BW, Pringle JSM, Maxwell NS, Richardson AJ. Altitude training in endurance running: perceptions of elite athletes and support staff. *J Sports Sci*. 2019;37(2):163–172. PubMed ID: 29932816 doi:10.1080/02640414.2018.1488383
33. Janse de Jonge XA, Thompson MW, Chuter VH, Silk LN, Thom JM. Exercise performance over the menstrual cycle in temperate and hot, humid conditions. *Med Sci Sports Exerc*. 2012;44(11):2190–2198. PubMed ID: 22776870 doi:10.1249/MSS.0b013e3182656f13