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RESEARCH PAPER

Effect of two-weeks endurance training wearing additional clothing in a temperate outdoor environment on performance and physiology in the heat

Christopher J. Stevens[a], Storme L. Heathcote[a], Daniel J. Plews[b], Paul B. Laursen[b], and Lee Taylor[c,d]

[a]School of Health and Human Sciences, Southern Cross University, Coffs Harbour, Australia; [b]Sport Performance Research Institute New Zealand (SPRINZ), Auckland University of Technology, Auckland, New Zealand; [c]Athlete Health and Performance Research Centre, ASPETAR, Qatar Orthopaedic and Sports Medicine Hospital, Doha, Qatar; [d]School of Sport, Exercise and Health Sciences, Loughborough University, Loughborough, UK

ABSTRACT

This investigation assessed performance, physiological and perceptual responses to wearing additional clothing during endurance training for two-weeks in temperate environments, to determine if this approach could be used as a practical, alternative, heat acclimation strategy for athletes. Fifteen trained male triathletes assigned to performance-matched groups completed a two-week unsupervised endurance cycling and running program in either (i) shorts and a short sleeve top (CON; n = 8) or (ii) additional clothing of full-length pants, a "winter" jacket and gloves made from nylon, polyurethane and polyester (AC; n = 7). Participants completed three separate (i.e. familiarisation, pre-program and post-program), identical, pre-loaded cycling time-trials (20 min at 180 W followed by a 40 min self-paced time trial) in 32.5 ± 0.1°C and 55 ± 6% RH. Core and skin temperatures, heart rate, sweat rate, perceived exertion, thermal sensation and thermal comfort were measured across the pre-loaded time trials, and heart rate and thermal sensation were measured across the training program. All of the participants recorded in their diaries that they completed all of the programmed training sessions in the required attire. Mean thermal sensation was *most likely* hotter in AC (5.5 ± 0.4 AU) compared to CON (4.4 ± 0.4 AU; ES = 1.61, ± 0.68) during the training sessions. However, follow up tests revealed no physiological or perceptual signs of heat acclimation, and the change in time-trial performance from pre-post between groups was trivial (CON: −3.5 ± 12.0 W, AC: −4.1 ± 9.6 W; difference = -0.7%, ± 5.4%). Training in additional clothing for two-weeks in a temperate environment was not an effective heat acclimation strategy for triathletes.

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Heat acclimation; heat acclimatisation; heat stress; heat training; restrictive heat loss attire; sweat clothing

Introduction

Repeated exercise training in a hot environment that induces beneficial thermoregulatory adaptations (heat acclimation/acclimatisation) is the principle counter-measure recommended to minimise heat-induced physiological strain, lower the incidence of heat-illness and improve athletic performance in the heat for endurance and team-sport athletes [1]. Training in the heat for ≥ 8 days has robust efficacy for ameliorating the hot environment-mediated declines in endurance performance [2]. The physiological adaptations responsible include lowered resting and exercising heart rate, lowered core and skin temperatures, plasma volume expansion, higher sweat rates and many others [2]. Consensus recommendations to induce heat acclimation are to exercise in the heat for at least 60 min daily, across 1–2 weeks, to provoke elevated physiological responses (namely increased cardiovascular strain, body temperatures and sweating) deemed central to acquiring the heat adapted phenotype [1,3].

The benefits of heat acclimation in advance of athletic competition in a hot environment are important, yet logistical challenges preclude some athlete's ability to train in the heat consistently. Indeed, only 13% of long distance athletes at the 2015 Beijing World Athletics Championships (where hot conditions were expected) followed a heat training regime [4]. A lack of access to a hot outdoor environment or suitable environmental chamber, costs associated with arriving earlier at events, combined with some athlete's aversion to stationary cycle ergometry or treadmill training,

CONTACT Lee Taylor Christopher.Stevens@scu.edu.au Lee.Taylor@aspetar.com School of Health and Human Sciences, Southern Cross University, Coffs Harbour, Australia, Athlete Health and Performance Research Centre, ASPETAR, Qatar Orthopaedic and Sports Medicine Hospital, Doha, Qatar

are likely some of the reasons for the lack of heat training. Given many major endurance events are scheduled during northern hemisphere summer months, athletes residing in southern hemisphere winters can be presented with an obvious challenge (and vice versa in some instances). Hence, other empirically-informed strategies that can be used to acquire heat acclimation status are needed to support these athletes.

Application of additional clothing (overdressing) worn during endurance training has been suggested as a method that may induce heat acclimation in temperate environments [5]. Overdressing can significantly increase thermoregulatory strain during laboratory endurance exercise [6–8] and outdoor cycling [9] in a temperate environment. For example, we recently showed that additional clothing (long pants, a jacket and gloves) worn during temperate outdoor cycling elicited moderate increases in mean core temperature and sweat rate [9], responses central to acquiring heat acclimation [3]. This overdressing approach during exercise over consecutive days has the potential to be a practical alternative to "traditional" heat training paradigms, yet unlike post-exercise hot-water immersion and sauna bathing [10–12] no studies have examined its efficacy for endurance athletes within a training study.

Current recommendations to obtain heat acclimation are built primarily on laboratory-based data[2] with little appreciation for "real-world" athlete training scenarios [13]. Further, heat-training programs described within the literature (e.g. the "controlled hyperthermia" or "controlled work rate" prescription methods) do not necessarily reflect the training style of most athletes in the field, limiting the transfer of such research into practice. Therefore, the current study aimed to test the hypothesis that endurance training in additional clothing (shown to acutely increase core temperature, sweating and heart rate [9]) for two-weeks would induce heat acclimation (as measured by reduced exercising core temperature and increased sweating responses) and improve endurance performance in the heat, using an ecologically-valid training program in a field-based setting.

Methods

Participants

Fifteen male triathletes (age: 43 ± 12 y, height: 177 ± 6 cm, body mass: 79 ± 11 kg, body fat percentage: 13.5 ± 5.0%) volunteered for the study. Inclusion criteria stipulated a current season's best sprint distance triathlon time of < 75 min (range = 65–74 min). Athletes were currently completing 5–9 bike and run training sessions with a combined minimum training duration of 8 h per week, which classified them as "*trained*" [14]. The Human Research Ethics Committee at Southern Cross University granted approval for the project in the spirit of the Helsinki Declaration and participants provided written informed consent prior to engaging in all procedures.

Experimental design

In this randomised control trial, a two-week outdoor cycling/running endurance-training program was employed. Three separate, identical, pre-loaded cycling time trials in a custom environmental chamber (made from a greenhouse; Maze, Clayton, VIC, Australia, and portable electric heater; Deelat Industrial, Redfern, NSW, Australia) at 32.5 ± 0.1°C and 55 ± 6% RH were completed by participants. The two-week program was preceded by two of the trials; a familiarisation time trial and a pre-program time trial, and the final time trial was conducted post-program.

Following the pre-program time trial, participants were assigned to one of two groups that either completed the training program in spandex shorts and a spandex short sleeve top (CON; n = 8; age = 47 ± 10 y; height = 176 ± 6 cm; body mass = 77 ± 13 kg) or additional clothing (AC; n = 7; age = 39 ± 14 y; height = 179 ± 6 cm; body mass = 82 ± 7 kg). In AC, participants wore full-length spandex pants, a spandex jersey, full-length gloves (made from a combination of nylon, polyurethane and polyester), as well as a jacket (made of 85% nylon, 15% elastane and polyester laminated; Sub Zero Cycling Jacket, 2XU, Melbourne, VIC, Australia). The dry mass of the additional clothing was 0.9–1.1 kg. The two groups were matched for pre-loaded 40 min cycling time trial performance in the heat (CON = 182 ± 15 W vs. AC = 184 ± 20 W) and body fat percentage (CON = 14.0 ± 5.5% vs. AC = 13.0 ± 4.0%). The pre-program time trial was completed 5–9 days after familiarisation, and the post-program time trial was completed 48 h after the conclusion of the training program.

Experimental trials

For 24 h prior to each trial, caffeine, alcohol and high intensity exercise were not permitted and participants were instructed to undergo their usual pre-race routine. During familiarisation, an anthropometric profile was obtained from each participant consisting of stature (217 stadiometer, Seca, Birmingham, UK), body mass (DS-530 electronic scales, Wedderburn, Sydney, Australia) and sum of 7 skinfolds (Harpenden Calipers, Baty International, West Sussex, UK), with estimation of body density [15] and fat percentage [16].

$$mean\ skin\ temperature = 9.429 + (0.137 * forehead) + (0.102 * hand) + (0.29 * back) + (0.173 * calf)$$

The trials consisted of 20 min at 180 W immediately followed by a 40 min self-paced time trial (coefficient of variation = 1.7%) [17] where power output was determined with a Wahoo KICKR power-trainer (Wahoo Fitness, Atlanta, USA), which has been validated previously [18]. During the trials, a 40 cm fan was placed 1 m in front of the bike and provided a wind speed of 8 m.s^{-1} to simulate the convective cooling of outdoor cycling [19]. Trials were conducted at the same time of day with no food, supplements or music permitted. *Ad libitum* room temperature water at 33°C was consumed to ensure that thermoregulatory and perceptual variables were not confounded within participants by ingestion of cold fluid during the trials. Footwear, clothing and instruction were standardised between all trials.

Measures

Power output and heart rate were continuously measured at 1 Hz by a Garmin Forerunner 920XT monitor (Garmin Ltd., Schaffhausen, Switzerland) that was connected to the power-trainer and a chest strap by ANT+ (ANT wireless, Alberta, Canada). Mean measures were also recorded at 10 min intervals. Towel dried nude mass was measured before and after each trial, which was corrected for fluid ingestion to estimate sweat rate (L.h^{-1}) via the following equation:

$$sweat\ rate = (\Delta mass + fluid\ ingested)/exercise\ time$$

Core temperature was measured every 30 s by an indigestible telemetric capsule (e-Celsius Performance, BodyCAP, Caen, France) consumed 8 h prior to arrival and calibrated as described previously [20]. Skin temperatures at the forehead, dorsum of hand, lower back and calf were measured every 10 min with a dermal thermometer (DermaTemp, Exergen, Massachusetts, USA) so that mean skin temperature could be estimated via the following equation [21]:

Rating of perceived exertion (RPE) was measured using the category ratio-10 scale where 0 = rest and 10 = maximal [22]. Mean thermal sensation was measured using Young's 17-point category ratio scale, where 0 = unbearably cold and 8 = unbearably hot [23], and mean thermal comfort was measured using a modified 10-point category ratio scale where 1 = comfortable and 10 = extremely uncomfortable [24]. Ambient temperature and relative humidity were recorded every 10 min during the trial with a handheld portable weather metre (accuracy = ± 0.8°C and 4% RH; PCE-THB 40, PCE instruments, Alicante, Spain).

Training program

The training program was developed by a Triathlon Australia accredited Level 2 (Performance) triathlon coach, after consultation with the recruited athletes to ensure that the program met their needs. The specific training program developed was endorsed by the athlete (and coach when necessary) as being representative of their training across the last two months, in regard to frequency, intensity and duration. It consisted of three individual cycling sessions, two individual running sessions, a combined cycle/run session and a rest day per week for two-weeks. The training sessions included a mixture of long slow distance, threshold and interval workouts with intensity prescribed as RPEs of 3–7, as described in Table 1. Best estimates of minimum training intensity (i.e. RPE '3a') was 50–55% of maximal oxygen uptake, with the majority of training completed (i.e. RPE '4-5a') estimated to be equivalent to 58–64% of maximal oxygen uptake, based on previous observations in fit individuals [25] and RPE scale transformation [22]. The program was completed outdoors and was mostly unsupervised by the research team. All sessions were completed in the spring months on the mid-north coast of Australia [September-November; ~ 18°C (range = 11.3–23.6°C) and ~ 67% RH (range = 51.8–80.1% RH)]. Participants were asked to follow their usual swimming routine during this time. No exposure to hot-water immersion or sauna (or similar) was permitted for 4 weeks prior to, or during the study.

For each training session, the participant recorded the ambient temperature and relative humidity upon starting and finishing through a smart phone application receiving information from the local weather station (Weatherzone). The session duration, mean RPE [22] mean thermal sensation and mean heart rate (Garmin Forerunner 920XT, Garmin Ltd., Schaffhausen, Switzerland) were also recorded by the participant. Training load was calculated with the session RPE method via the following equation [26]:

$$session\ RPE = session\ duration\ (min)\ xRPE(AU)$$

Core temperature, sweat rate and heart rate were measured (with the procedures described above) during one training session (both with and without AC) in a subset of the participants, as reported in an accompanying article [9].

Table 1. Weekly training program.

Day	Session Details
Mon	Bike Intervals. W/U: 15 min moderate, 5 min build from moderate to hard. M/S: 4 × 6 min very hard with 2 min rest interval between each. C/D: 20 min moderate (70 min total)
Tue	Run. W/U: 10 min walk and drills. M/S: 45 min moderate-somewhat hard. C/D: 5 min walk (60 min total)
Wed	Bike Race Pace. W/U: 15 min moderate, 5 min build from moderate to hard. M/S: 40 min hard continuous, C/D: 10 min moderate (70 min total)
Thu	Rest Day
Fri	Run. W/U: 10 min walk and drills. M/S: 45 min moderate-somewhat hard. C/D: 5 min walk (60 min total)
Sat	Bike long slow distance. 2 h moderate-somewhat hard (120 min total)
Sun	Bike/Run threshold brick. W/U: 10 min bike moderate. M/S: 50 min hard bike with 30 min hard run off bike. C/D: 5 min moderate run (95 min total)

W/U = warm-up, M/S = main set, C/D = cool-down. Descriptors of "moderate", "hard" etc. are based on the CR-10 rating of perceived exertion scale. Note: This program was repeated for 2-weeks.

Statistical analysis

Measurements are presented as mean± standard deviation and 90% confidence limits and were analysed using a contemporary magnitude-based inference approach [27]. For the change in cycling time trial performance, the smallest important effect is 1% (after log transformation i.e. 100 x natural log) and for the change in physiological responses, the smallest important effect was taken from a previous meta-analysis [2]. For comparisons of training summary statistics and physiological responses, the magnitude of the changes between trials were expressed as standardised differences (effect sizes; ES). The criteria used for interpreting the magnitude of the ES were: ≤ 0.2 trivial, > 0.2 small, > 0.6 moderate, > 1.2 large and > 2.0 very large [27]. These differences, with uncertainty of the estimates shown as 90% confidence limits, were determined using published spreadsheets available at sportsci.org [27]. If the 90% confidence limits overlapped both substantial increases and decreases, the effect was deemed unclear. Quantitative chances of the true effect being substantial were also assessed qualitatively as follows: < 1%, most unlikely; 1–5%, very unlikely; 5–25%, unlikely; 25–75%, possibly; 75–95%, likely; 95–99%, very likely; > 99% most likely [27].

For the change in perceptual responses, an approach called full-scale deflection was adopted since the data had a known endpoint (i.e. the end of the scale). Magnitude-based thresholds were used to determine the smallest worthwhile change (10%) for each perceptual variable [28]. A range was made from 0–100% and magnitude thresholds were defined as 10%, 30%, 50%, 70% and 90% for small, moderate, large, very large and extremely large changes, respectively [29]. When an effect was > 5% for both substantial increases and decreases, the true value of the difference was deemed unclear.

Results

Training program

All of the participants recorded in their diaries that they completed all of the programmed training sessions in the required attire. Mean thermal sensation was *most likely* hotter during training in AC (5.5 ± 0.4 AU) compared to CON (4.4 ± 0.4 AU; ES = 1.61, ± 0.68; large difference). There was no clear difference between groups in total training duration (869 ± 132 min and 824 ± 98 min for AC and CON, respectively; ES = 0.37 ± 0.96), RPE (5.2 ± 1.0 AU and 4.9 ± 1.2 AU for AC and CON, respectively; ES = 0.25, ± 0.75), session RPE (4576 ± 1487 AU and 3972 ± 822 AU for AC and CON, respectively; ES = 0.52, ± 1.16) or heart rate (139 ± 13 bpm and 139 ± 12 bpm for AC and CON, respectively; ES = 0.03, ± 0.94). There were also no clear differences observed for the mean outdoor training temperature (18.5 ± 3.4°C and 17.6 ± 4.1°C for CON and AC, respectively; ES = -0.31, ± 1.05) and relative humidity (66.7 ± 11.0 and 67.1 ± 12.0 for CON and AC, respectively; ES = 0.03, ± 1.00). The core temperature, sweat rate and heart rate were increased while wearing AC, as described previously in a subset of the participants [9].

Laboratory testing

The change in 40 min time-trial performance from pre-post between groups was trivial and unclear (CON: −3.5 ± 12.0 W, AC: −4.1 ± 9.6 W; difference = -0.7%, ± 5.4%). Figure 1 illustrates the mean power outputs for all trials, and individual responses demonstrate that the majority of participants in AC (5/7) did not improve following the training program. There were no changes in this outcome when the performance data were adjusted for training load and/or baseline testing performance. There were also no differences in mean power output between conditions when the data were divided into 10-minute intervals.

The mean physiological responses between conditions are presented in Table 2 and the mean perceptual responses are presented in Table 3. These tables demonstrate the results of the various measures, and are separated into the fixed intensity and time trial portions of the pre-program and post-program trials. While there were some differences between conditions, evaluation of the within condition responses (i.e. pre-post) revealed that any between condition differences were trivial.

The core body temperature responses (where the data were divided into 10-minute intervals) are illustrated in Figure 2. There were no

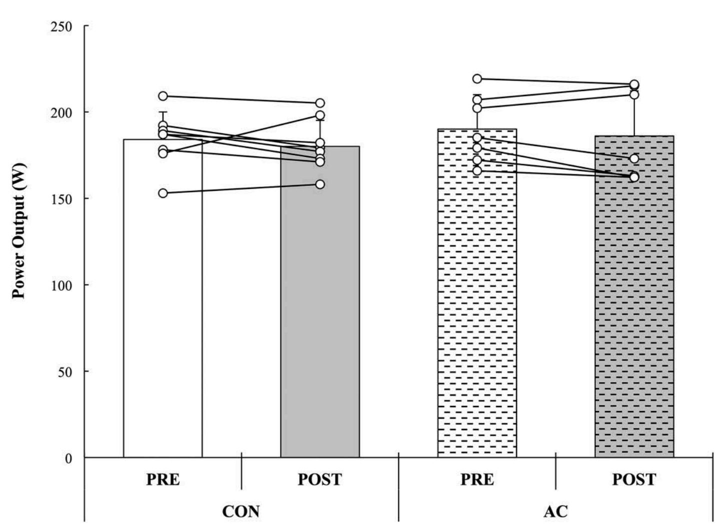

Figure 1. Mean power output between control (CON; solid columns) and additional clothing (AC; dashed columns) for the 40-minute time trials during PRE (white columns) and POST (grey columns) tests.

Table 2. Physiological responses during laboratory testing, and standardised differences in the additional clothing (AC) compared to the control (CON) group.

Variable		CON Mean± SD	AC Mean± SD	Effect Size	90% CL	Qualitative ES
Pre-load Tc (°C)	PRE	37.4 ± 0.3	37.2 ± 0.4	−0.42	−1.32 to 0.47	Unclear
	POST	37.4 ± 0.3	37.4 ± 0.4	−0.11	−1.01 to 0.78	Unclear
Time trial T_C (°C)	PRE	38.1 ± 0.5	37.9 ± 0.5	−0.31	−1.21 to 0.58	Unclear
	POST	38.2 ± 0.4	38.1 ± 0.4	−0.12	−1.02 to 0.78	Unclear
Pre-load T_{MS} (°C)	PRE	31.7 ± 0.6	31.7 ± 0.7	−0.12	−1.27 to 1.02	Unclear
	POST	31.7 ± 0.6	31.8 ± 0.4	0.23	−0.02 to 1.35	Trivial
Time trial T_{MS} (°C)	PRE	31.9 ± 0.4	32.2 ± 0.4	0.43	−0.72 to 1.58	Unclear
	POST	31.9 ± 0.4	32.3 ± 0.1	1.22	0.13 to 2.31	Large
Pre-load heart rate (bpm)	PRE	130 ± 8	121 ± 8	−1.03	−1.93 to −0.13	Large
	POST	130 ± 10	124 ± 8	−0.60	−1.49 to 0.29	Unclear
Time trial heart rate (bpm)	PRE	143 ± 11	139 ± 9	−0.36	−1.26 to 0.54	Unclear
	POST	145 ± 15	143 ± 6	−0.18	−1.04 to 0.68	Unclear
Sweat rate ($L·h^{-1}$)	PRE	1.4 ± 0.2	1.6 ± 0.3	0.2	−0.1 to 0.5	Trivial
	POST	1.5 ± 0.2	1.6 ± 0.2	0.1	−0.1 to 0.3	Trivial

bpm = beats per minute, CL = confidence limits, ES = effect size, PRE = pre-program trial, Pre-load = 20-min fixed intensity portion of the trial, POST = post-program trial, SD = standard deviation, T_C = core temperature, T_{MS} = mean skin temperature, time trial = 40 min time trial portion of the trial.

Table 3. Perceptual responses during laboratory testing, change in the mean and qualitative change in the additional clothing (AC) compared to the control (CON) group.

Variable		CON Mean± SD	AC Mean± SD	Change in mean (%)	90% CL	Qualitative Change
Pre-load RPE (AU)	PRE	3.8 ± 0.6	3.1 ± 0.5	−17.1	−17.1 to 29.2	*Unclear*
	POST	4.1 ± 0.6	3.3 ± 0.4	−23.2	−36.2 to −7.6	*Unclear*
Time trial RPE (AU)	PRE	6.0 ± 0.7	5.3 ± 1.3	−15.5	−35.8 to 11.4	*Unclear*
	POST	6.5 ± 0.8	5.7 ± 1.6	−16.6	−38.3 to 12.7	*Unclear*
Pre-load TS (AU)	PRE	5.2 ± 0.4	4.9 ± 0.3	−5.1	−12.3 to 2.7	*Most likely negative*
	POST	5.4 ± 0.5	5.0 ± 0.4	−8.6	−17.7 to 1.5	*Most likely negative*
Time trial TS (AU)	PRE	6.0 ± 0.4	5.7 ± 0.7	−6.6	−16.8 to 4.8	*Very likely negative*
	POST	6.2 ± 0.5	5.7 ± 0.7	−10.1	−19.7 to 0.8	*Most likely negative*
Pre-load TC (AU)	PRE	3.3 ± 1.1	3.2 ± 1.0	−0.7	−35.3 to 52.4	*Unclear*
	POST	3.8 ± 1.0	3.1 ± 0.6	−23.4	−43.1 to 3.1	*Very likely negative*
Time trial TC (AU)	PRE	5.4 ± 1.2	5.1 ± 0.7	−4.7	−23.3 to 18.5	*Unclear*
	POST	6.1 ± 1.0	5.4 ± 1.4	−17.1	−36.8 to 7.3	*Unclear*

AU = arbitrary units, CL = confidence limits, PRE = pre-program trial, Pre-load = 20-min fixed intensity portion of the trial, POST = post-program trial, SD = standard deviation, RPE = rating of perceived exertion, TC = thermal comfort, TS = thermal sensation, time trial = 40 min time trial portion of the trial.

differences between conditions at any time-point for these measures.

Discussion

Despite the greater thermal sensation observed in the AC condition during training, and previous reports of increased core temperature, heart rate and sweating with AC in the same scenario and a subset of the same participants [9], this strategy did not result in heat acclimation (i.e. no evidence of lower exercising core temperature or heart rate, or increased sweat rate) or performance enhancement in the heat compared to the CON condition. Indeed, the majority of participants did not improve their cycling performance following the training program in AC. Thus, we can assume that the thermal stimulus provided via AC, combined with the load of the training duration and intensity, was not appropriate to induce the heat acclimation or performance improvements that are typically found with laboratory-based protocols [30–32].

The failure of the AC intervention to induce any signs of heat acclimation may be attributed to several factors. First, it is possible that the clothing itself and its interaction with the programmed training duration and intensity, did not allow achievement of the thermo-physiological strain thresholds required to elicit heat

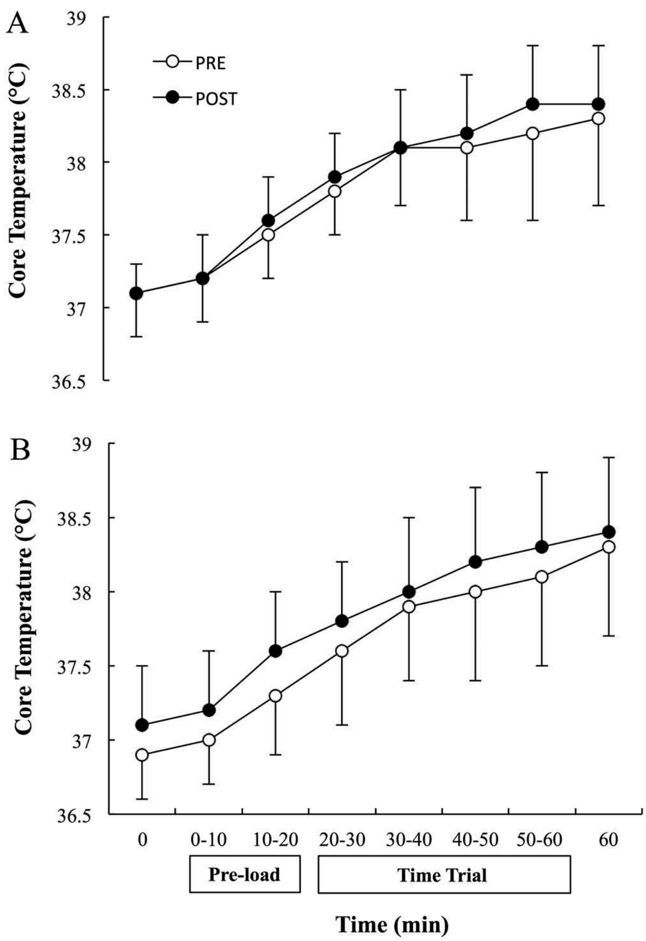

Figure 2. Core body temperature at 10-minute intervals across the cycling protocol for control (A) and additional clothing (B) during PRE (white circles) and POST (black circles) tests.

acclimation (which are not currently well-described in the literature). While we have shown that AC can increase thermo-physiological strain beyond training in regular attire, such strain is likely to be less than that experienced in very hot and wind-still laboratory conditions (i.e. the setting of traditional heat acclimation studies). Likewise, lower thermo-physiological strain may also be attributed to the outdoor setting, where a high convection (and associated cooling) load was present. Further, the variable ambient temperature was sometimes as low as 11°C, which meant that the AC was sometimes needed simply to maintain normal body temperature, and therefore unlikely to induce a heating effect at such times. These practical challenges should be addressed in further research; manipulations of training session prescription (duration, intensity and frequency) as well as using clothing with variable insulation may be required to increase the thermal stimulus when overdressing during exercise in a temperate environment.

One further explanation for the null performance effect in the current study could be the thermal demands of the pre-loaded cycling time trial. Despite being of 1-hour duration in hot conditions, the athletes only achieved a maximum core temperature of approximately 38.5°C (Figure 2). It is common for triathletes to compete over longer exercise durations, in hotter environments, and the addition of running after cycling would also increase the thermoregulatory requirements of a triathlon event. At hotter body temperatures, the effects of heat acclimation training and potentially the benefits of training in additional clothing may have been apparent.

Other practical heat acclimation strategies including post-exercise hot water immersion [12] and sauna exposure [11,33] have been shown to elicit heat acclimation and enhance endurance exercise performance in the heat. However, the magnitude of adaptation appears less favourable with these practical approaches compared to traditional laboratory exercise scenarios [10]. Additionally, recovery time from training and time available for training are both reduced with these practical approaches, and the thermal exposures themselves represent an additional training load; something that could conflict with prioritised training, recovery and/or taper phase objectives [11]. Recommendations for the seamless integration of classical (laboratory) and field-based heat training, which also considers the training phase objective, remains an unresolved ambition of practitioners [11].

The "real world" design of the current study aimed to allow this research to be easily translated to practice. While external validity was maximised, internal validity was compromised at times. Firstly, the design meant that the research team could not access the participants to appropriately measure core temperature during all of the training sessions. However, an acute cross-over study with the same intervention, training scenario and with a subset of the same participants provided a suitable indication of the heating capacity of the AC intervention [9]. It should also be noted that we could not confirm independently that the athletes followed the training program or wore the additional clothing in all circumstances, however, participants self-reported 100% adherence to the clothing and the training program criteria on all rides (as per their training diaries). Additionally, the majority of the training sessions were completed in small groups (but always non-drafting) so compliance or not, was often overt within participants. Finally, the clear difference in thermal sensation between conditions is further evidence that the athletes in the AC group wore the additional clothing. Finally, the study could have been improved through measurement of external and internal training load. While the subjective training load did not differ between groups, it is possible that the training intensity was reduced with the AC intervention.

Conclusion

The application of standard winter training garments (additional clothing) when cycling and running outdoors within a temperate environment resulted in increased thermo-physiological strain and hotter thermal sensations. Despite this, training for two-weeks in additional clothing did not induce heat acclimation (i.e. no evidence of lowered exercising core temperature or heart rate, or increased sweat rate) or improve cycling performance in the heat.

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Abbreviations

AU	Arbitrary units
AC	Additional clothing trial
bpm	Beats per minute
CON	Control trial
ES	Effect size
RPE	Rating of perceived exertion
RH	Relative humidity

Disclosure statement

No potential conflict of interest was reported by the authors.

References

[1] 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.

[2] Tyler CJ, Reeve T, Hodges GJ, et al. The effects of heat adaptation on physiology, perception and exercise performance in the heat: a meta-analysis. Sports Med. 2016;46(11):1699–1724.

[3] Taylor NA. Human heat adaptation. Comp Physiol. 2014;4(1):325–365.

[4] Periard JD, Racinais S, Timpka T. 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.

[5] Stevens CJ. Evidence for training in additional clothing as an alternative heat acclimation strategy for athletes. Temperature. 2018;5:101–102.

[6] Dawson B, Pyke FS, Morton AR. Improvements in heat tolerance induced by interval running training in the heat and in sweat clothing in cool conditions. J Sports Sci Winter. 1989;7(3):189–203.

[7] Ely BR, Blanchard LA, Steele JR, et al. Physiological responses to overdressing and exercise-heat stress in trained runners. Med Sci Sports Exerc. 2018;50(6):1285–1296.

[8] Willmott AGB, Gibson O, James CA, et al. Physiological and perceptual responses to exercising in restrictive heat loss attire with use of an upper-body sauna suit in temperate and hot conditions. Temperature. In Press.

[9] Stevens C, Plews DJ, Laursen P, et al. Acute physiological and perceptual responses to wearing additional clothing while cycling outdoors in a temperate environment: a practical method to increase the heat load. Temperature. 2017;4(2):414–419.

[10] Periard JD, Travers GJS, Racinais S, et al. Cardiovascular adaptations supporting human exercise-heat acclimation. Auton Neurosci. 2016;196:52–62.

[11] Casadio JR, Kilding AE, Cotter JD, et al. From lab to real world: heat acclimation considerations for elite athletes. Sports Med. 2017;47(8):1467–1476.

[12] Zurawlew MJ, Walsh NP, Fortes MB, et al. 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.

[13] Racinais S, Periard JD, Karlsen A, et al. Effect of heat and heat-acclimatization on cycling time-trial performance and pacing. Med Sci Sports Exerc. 2015;47(3):601–606.

[14] De Pauw K, Roelands B, Cheung SS, et al. Guidelines to classify subject groups in sport-science research. Int J Sports Physiol Perform. 2013;8(2):111–122.

[15] Withers RT, Craig NP, Bourdon PC, et al. Relative body fat and anthropometric prediction of body density of male athletes. Eur J Appl Physiol Occup Physiol. 1987;56(2):191–200.

[16] Siri WE. The gross composition of the body. Adv Biol Med Phys. 1956;4:239–280.

[17] Zavorsky GS, Murias JM, Gow J, et al. Laboratory 20-km cycle time trial reproducibility. Int J Sports Med. 2007;28(9):743–748.

[18] Hoon MW, Michael SW, Patton RL, et al. A comparison of the accuracy and reliability of the Wahoo KICKR and SRM power meter. J Sci Cycling. 2016;5(3):11–15.

[19] Saunders AG, Dugas JP, Tucker R, et al. 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.

[20] Travers GJ, Nichols DS, Farooq A, et al. Validation of an ingestible temperature data logging and telemetry system during exercise in the heat. Temperature. 2016;3(2):208–219.

[21] Nielsen R, Nielsen B. Measurement of mean skin temperature of clothed persons in cool environments. Eur J Appl Physiol Occup Physiol. 1984;53(3):231–236.

[22] Borg GA. Borg's perceived exertion and pain scales. Champaign, Illinois: Human Kinetics; 1998.

[23] Young AJ, Sawka MN, Epstein Y, et al. Cooling different body surfaces during upper and lower body exercise. J Appl Physiol. 1987;63(3):1218–1223.

[24] Gagge AP, Stolwijk JA, Hardy JD. Comfort and thermal sensations and associated physiological responses at various ambient temperatures. Environ Res. 1967;1(1):1–20.

[25] Travlos AK, Marisi DQ. Perceived exertion during physical exercise among individuals high and low in fitness. Percept Mot Skills. 1996;82(2):419–424.

[26] Foster C, Florhaug JA, Franklin J, et al. A new approach to monitoring exercise training. J Strength Cond Res. 2001;15(1):109–115.

[27] Hopkins W, Marshall S, Batterham A, et al. Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc. 2009;41(1):3–13.

[28] Casadio JR, Storey AG, Merien F, et al. Acute effects of heated resistance exercise in female and male power athletes. Eur J Appl Physiol. 2017;117(10):1965–1976.

[29] Hopkins WG. Linear models and effect magnitudes for research, clinical and practical applications. Sport Science. 2010;14(1):49–57.

[30] Nielsen B, Strange S, Christensen NJ, et al. Acute and adaptive responses in humans to exercise in a warm, humid environment. Pflugers Arch. 1997;434(1):49–56.

[31] Nielsen B, Hales JR, Strange S, et al. Human circulatory and thermoregulatory adaptations with heat acclimation and exercise in a hot, dry environment. J Physiol. 1993;460:467–485.

[32] Lorenzo S, Halliwill JR, Sawka MN, et al. Heat acclimation improves exercise performance. J Appl Physiol. 2010;109(4):1140–1147.

[33] Scoon GS, Hopkins WG, Mayhew S, et al. Effect of post-exercise sauna bathing on the endurance performance of competitive male runners. J Sci Med Sport. 2007;10(4):259–262.