1 **Short-term heat acclimation and precooling, independently and**

2 **combined, improve 5 km running performance in the heat.**

3

4 **ABSTRACT**

5 Following heat acclimation (HA), endurance running performance remains impaired in hot vs

6 temperate conditions. Combining HA with precooling demonstrates no additive benefit in intermittent

7 sprint, or continuous cycling exercise protocols, during which heat strain may be less severe compared

8 to endurance running. This study investigated the effect of short-term heat acclimation (STHA)

9 combined with mixed-methods precooling, on endurance running performance and directly compared

10 precooling and HA. Nine amateur trained runners completed 5 km treadmill time trials in the heat

11 (32°C, 60% RH) under four conditions; no intervention (CON), precooling (PC), short-term heat

12 acclimation (5 days - HA) and short-term heat acclimation with precooling (HA+PC). Mean (±SD)

13 performance times were; CON 1476 (173) s, PC 1421 (146) s, HA 1378 (116) s and HA+PC 1373 (121)

14 s. This equated to the following improvements versus CON; PC -3.7%, HA -6.6% and HA+PC -7.0%.

15 Statistical differences were only observed between HA and CON (p=0.004, d=0.68, 95% CI [-0.27, 1.63])

16 however, similar effect sizes were observed for HA+PC vs CON (d=0.70, 95% CI [-0.25, 1.65]), with

17 smaller effects between PC vs CON (d=0.34, 95% CI [-0.59, 1.27]), HA vs PC (d=0.33, 95% CI [-0.60,

18 1.26]) and HA+PC vs PC (d=0.36, 95% CI [-0.57, 1.29]). Pilot testing revealed a time trial typical error

19 of 16 s (1.2%). Precooling offered no further benefit to performance in the acclimated individual,

20 despite modest alleviation of physiological strain. Maintenance of running speed in HA+PC, despite

21 reduced physiological strain, may indicate an inappropriate pacing strategy therefore, further

22 familiarisation is recommended to optimise a combined strategy. Finally, these data indicate HA,

23 achieved through cycle training, yields a larger ergogenic effect than precooling on 5km running

24 performance in the heat, although precooling remains beneficial when HA is not possible.

Combining heat acclimation and precooling for running in the heat.

1 **Key words**

2 Hyperthermia; endurance; lactate threshold; $\dot{V}O_{2max}$; heat stress, thermoregulation.

3 **INTRODUCTION**

4   Strategies to alleviate the deleterious effect of hyperthermia on endurance performance

5 habitually adopt a uni-dimensional approach, with athletes advised to either precool or undertake

6 heat acclimation (HA) [1]. This dichotomous practice persists despite a dearth of direct comparisons

7 between acute and chronic strategies, that would indicate the most effective approach.

8   From a chronic perspective, HA is habitually classified as either short (STHA, <7 days), medium

9 (MTHA, 8-14 days) or long term (LTHA, >15 days) [2]. Heat acclimation induces observable and

10 prominent adaptations including decreased resting and exercising, core (T_{CORE}) and skin (T_{SKIN})

11 temperatures, alongside a reduction in exercising heart rate (HR), which likely arises through an

12 expanded plasma volume [3]. Typical ergogenic effects of STHA on endurance performance are reported

13 to be 2.4% [4]. Such adaptations help mitigate against an accentuated cardiovascular challenge during

14 exercising under heat stress, which notably reduces maximal oxygen uptake ($\dot{V}O_{2max}$) as a consequence

15 of thermoregulatory cutaneous vasodilation impeding venous return and cardiac filling [5]. However,

16 evidence demonstrates both endurance performance [6] and $\dot{V}O_{2max}$ [7] remain impaired in the heat

17 following HA, relative to cooler conditions (13°C vs 38°C [6], 21°C vs 49°C [7]), highlighting not only the

18 persistence of heat strain, but a need to further improve endurance performance in the acclimated

19 individual.

20   Acute, precooling techniques may be classified as internal (e.g. ice slurry ingestion) or external

21 (e.g. ice vests, ice packs), depending upon how the cooling impulse is delivered. External precooling

22 demonstrates larger effects on T_{SKIN} and thermal sensation than internal precooling [8]. External

23 precooling presents a dose-dependent response, with a mixed-methods approach, involving multiple

24 cooling garments and hand/forearm cold water immersion appearing preferable to singular cooling

Combining heat acclimation and precooling for running in the heat.

1   garments, due to the greater cooled skin surface area[9]. Accordingly, recent meta-analyses report large

2   effects on subsequent endurance performance when multiple cooling garments are worn either

3   alongside or following part-body cold water immersion (+7.3%, d =0.72 [10], d = 1.91 [11]). Of note, the

4   practical mixed methods technique of Duffield et al. [12], involving ice towels, ice packs, ice vest and

5   hand immersion in cold water, ameliorates physiological and thermoregulatory strain during fixed

6   intensity endurance exercise in the heat [8], but has yet to be evaluated during free-paced exercise,

7   where the influence of alterations in T_{SKIN} and thermal perception may be most pronounced [13].

8   Despite individual strategies failing to maintain endurance performance in the heat relative to

9   normothermic conditions, the benefit of combining interventions is yet to be fully elucidated. Castle

10   et al.[14] reported no additional benefit from quadriceps precooling during intermittent sprint-cycling,

11   following LTHA. Results indicated LTHA alone sufficiently negated heat strain during this type of

12   activity. Consequently, Brade et al. [15] investigated precooling following STHA, which affords only

13   partial heat adaptation in comparison to LTHA [24]. However, no additive effect was observed, with STHA

14   again mediating heat strain during intermittent sprinting sufficiently such that precooling was

15   unwarranted and thus ineffective. Conversely, continuous running or cycling endurance exercise in

16   the heat confers a large and consistent physiological strain [16], which may therefore require a more

17   potent intervention than HA alone to ameliorate declines in performance. This notion is reinforced by

18   larger effects of precooling observed on endurance performance, compared with intermittent

19   sprinting [11].

20   Recently Schmit et al. [17] investigated national-level triathletes wearing ice vests at rest and during

21   the warm-up prior to a 20 km cycling time trial, following 10-days of acclimatisation. Although the

22   addition of precooling did not improve performance above acclimatisation alone, transient, beneficial

23   pacing alterations were observed during the first half of the trial, alongside improved perceived

24   thermal strain, following precooling. Therefore, a more potent precooling strategy e.g. mixed

25   methods[12], may magnify or prolong this transient benefit. This transient benefit may also be more

26   impactful in a shorter event than the ~32 min trial of Schmit et al. [17], as the effects of precooling will

Combining heat acclimation and precooling for running in the heat.

1   be experienced for a greater proportion of the event duration before dissipating. A further

2   consideration is the type of exercise undertaken, with exercise such as running, that yields a significant

3   metabolic heat production (MHP) appearing best suited to combining interventions, given heat strain

4   can be mitigated by STHA alone during intermittent sprinting whilst cycling [15]. Running elicits a greater

5   MHP than cycling and provides less convective cooling [18,19], which collectively expedites heat strain,

6   relative to cycling [20]. Therefore, when STHA is adopted, affording partial heat adaptation, an additive

7   effect from precooling may be observed when heat strain remains high during exercise such as

8   endurance running. However, no investigations have combined precooling and HA prior to endurance

9   running.

10   Therefore, the aim of this study was to investigate whether mixed methods external precooling

11   following STHA provided greater ergogenicity for maintaining endurance running performance, than

12   STHA alone, whilst providing a direct comparison between precooling and heat acclimation. It was

13   hypothesised that combining STHA and precooling would improve time trial performance relative to

14   STHA, whilst STHA would be more beneficial than precooling alone.

15   **METHODS**

16   **Experimental approach to the problem**

17   A repeated measures design was adopted, with individuals completing two 5 km treadmill time

18   trials and a graded exercise test (GXT) before and after 5 days of STHA, as shown in Figure 1. Each GXT

19   was ordered immediately pre and post HA training, whilst time trials (TT) with either precooling (PC)

20   or a no intervention control trial (CON) were completed in a counterbalanced order, prior to STHA.

21   Experimental trials occurred at least 10 days after instrumented familiarisations of the GXT and TT in

22   the heat. Following STHA, a TT was completed without precooling (HA) and another with precooling

23   (HA+PC), again counterbalanced (Figure 1). Trials occurred at a similar time of the day to minimise

24   fluctuation in thermoregulatory responses from circadian variation [21].

Combining heat acclimation and precooling for running in the heat.
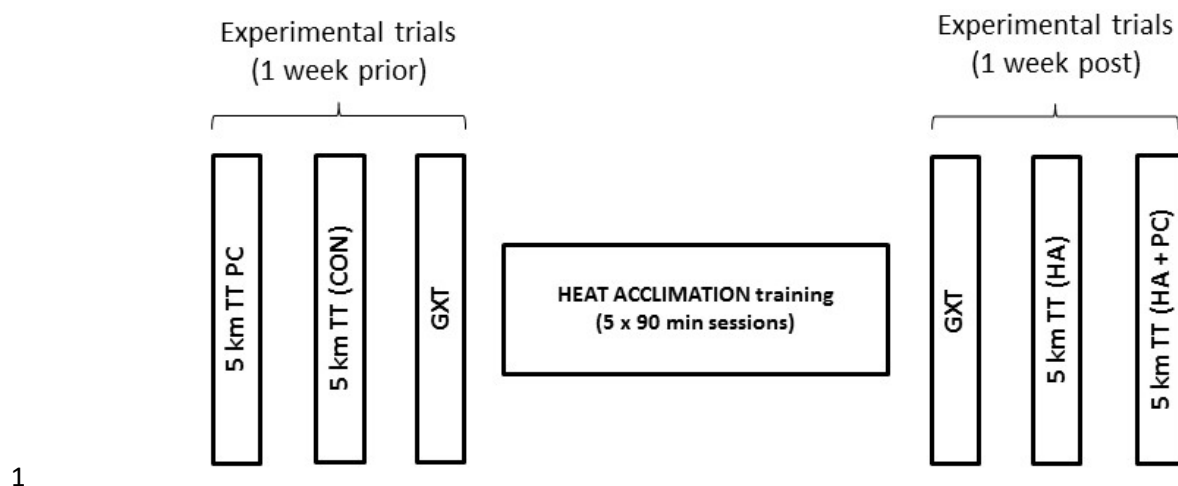
1

2   Figure 1: Overview of experimental design. 'GXT' = Graded exercise test. 'TT' = time trial. 'PC =

3   precooling. 'CON' = no intervention control. 'HA' = heat acclimation. 'HA+PC' = Heat acclimation and

4   precooling. All trials completed in the heat. Before training, five participants completed CON first and

5   four completed precooling first. After training, five completed HA first and four completed HA+PC first.

6   **Subjects**

7   Nine amateur, club runners (8 male, 1 female), who had trained at least three times per week for

8   the previous 2 months, volunteered for this study (mean [±SD]: age 32 [16] years, stature 175 [7] cm,

9   mass 71.9 [8.8] kg, sum of four skinfolds 25.4 [3.8] mm, $\dot{V}O_{2max}$ 59.1 [6.9] mL.kg^{-1}.min^{-1}, recent 5km

10   time: 20:44 [1:44] min). Participants were recruited as part of a larger study on heat acclimation [22]. All

11   participants had completed a sub-22 min 5km or sub 45 min 10km race in the previous 2 months and

12   had never previously undertaken HA. The female participant completed pre-tests and training during

13   the follicular phase of the menstrual cycle, with post-tests during the first 5 days of luteal phase.

14   Participants were informed of the benefits and risks of the investigation prior to signing an

15   institutionally approved informed consent document to participate in the study. Ethical approval was

16   issued in accordance with the Declaration of Helsinki (2013). Participants arrived hydrated, having

17   refrained from intense exercise for 48 hours, and avoided alcohol and caffeine for 24 hours.

18   Participants completed a 24-hour food diary prior to each test and indicated sleeping hours,

19   motivation, muscle soreness and stress on 5-point Likert scales upon arrival.

Combining heat acclimation and precooling for running in the heat.

1 **Procedures**

2 **Precooling**

3   A mixed-methods, external precooling technique was adopted, as per Duffield et al. [12] and James

4 et al. [8]. This involved wet, iced towels covering the head and neck, forearm and hand immersion in

5 cold water (9°C), an ice vest (Artic Heat, Australia) on the torso and ice packs affixed to the quadriceps

6 using cooling shorts, across a 20 min seated period. Towels were changed after 10 min and hand

7 immersion water temperature was actively maintained throughout.

8 **Heat acclimation**

9   Heat acclimation involved five, 90 min daily training sessions in the heat (~37°C, ~60% relative

10 humidity [RH]) using controlled hyperthermia and permissive dehydration[23,24]. Participants exercised

11 on cycle ergometers (Monark, e724, Sweden) at an intensity initially prescribed relative to body mass,

12 at 2.7 W.kg^{-1} [25] and subsequently adjusted to maintain the maximum tolerable power to achieve the

13 target T_{CORE} (38.5°C) within 30 min. Upon T_{CORE} reaching 38.5°C, exercise was completed intermittently

14 to maintain T_{CORE} above 38.5°C for 60 min [23,24]. Throughout the training session, exercise intensity was

15 adjusted in 5 min blocks. Therefore, the typical work pattern was 30 min of continuous cycling, before

16 a further 5 min of exercise every 25 min. The initial prescription of exercise based on power output,

17 relative to body mass, as opposed to %$\dot{V}O_{2max}$ [14,26], removes the necessity for an initial cycling $\dot{V}O_{2max}$

18 test and maintains the relative exercise intensity across training days, independent of adaptation.

19 Furthermore, cycling training controlled for performance that could arise from increased training

20 volume were participants to acclimate through running. Training occurred at the same time of day,

21 predominantly in the morning (07:00-10:00 h) and one participant in the evening (18:00-20:00 h). No

22 fluid intake was permitted during training [27].

23

24

Combining heat acclimation and precooling for running in the heat.

1 **Exercise trials**

2 During all trials, participants initially rested in the hot environment (32°C, 60% RH) for 10 mins,

3 before a 20 min period for cooling, or additional rest, as appropriate. Therefore, the entire protocol

4 occurred within a thermostatically controlled environmental chamber (WatFlow control system TISS,

5 UK) within which conditions were continuously monitored throughout the trial using a heat stress

6 meter (HT30, Extech Instruments, USA), which provided indoor wet bulb globe temperature (WBGT).

7 A GXT in the heat, split into two parts; GXT 1 and GXT 2, was adopted similar to that described

8 by Jones [28] and as previously implemented [8,29]. The test comprised two parts; GXT 1, a submaximal

9 incremental speed protocol, followed by GXT 2; an incremental gradient protocol to volitional

10 exhaustion. During GXT 1 each participant completed a minimum of six stages, using speed increments

11 of 1 km.h^{-1}. The initial treadmill speed was based on the familiarisation trial, which in turn was

12 determined from recent 5 km time. Following a 10 min rest, GXT 2 began at a speed 2 km.h^{-1} below

13 the previous final speed with gradient increasing by 1% each min, continuing until volitional

14 exhaustion [28]. Participants were not permitted to drink and were blinded to all forms of feedback

15 throughout the duration of the trial.

16 Prior to completing any experimental TT, participants underwent a familiarisation trial under the

17 same circumstances. During the familiarisation, starting speed was determined based upon recent 5

18 km performance. For each experimental TT, following cooling and/or rest phases, participants

19 completed a self-selected 5 min warm-up, replicated across all trials, on a motorised treadmill

20 (Woodway ELG2, Germany). Standardised instructions were given at the start and nothing thereafter;

21 'give your all', 'pace yourself throughout the trial' and 'adjust speed as you see fit' as per similar studies

22 [30]. Participants straddled the treadmill belt, increased to the individual's average pace from the

23 familiarisation, to maintain a consistent blinded starting speed. Treadmill speed adjustment was

24 permitted *ad libitum* (increment 0.2 km.h^{-1}), with the distance completed continuously displayed.

25 Participants were blinded to all other feedback. Elapsed time was recorded every km.

Combining heat acclimation and precooling for running in the heat.

1 **Physiological measures**

2   During all trials, hydration was assessed upon arrival, whereby euhydration represented urine

3 osmolality and specific gravity below 700 mOsmol.kg^{-1} H$_2$O and 1.020, respectively [31]. Pre and post

4 nude body mass were recorded to estimate sweat loss (GFK150 scales, AE Adam, UK). A single-use

5 rectal probe (Henleys Medical, UK) connected to a meter logger (Model 401, Yellow Springs

6 Instruments, USA), was inserted 10 cm beyond the anal sphincter for T_{CORE} measurement. Telemetry

7 thermistors (U-Type connected to Gen II GD38 transmitter, Eltek, UK) were attached to the mid-belly

8 of the pectoralis major, biceps brachii, rectus femoris and gastrocnemius. Local skin temperatures

9 were derived through a datalogger (RX250AL 1000 series Wireless Squirrel Logger, Eltek) as per James

10 et al. [32] in order to determine mean T_{SKIN} [33]. Heart rate was monitored continuously using a Polar 810i

11 heart rate monitor (Kempele, Finland).

12   During the GXTs, HR, T_{CORE}, T_{SKIN}, rating of perceived exertion (RPE [34]) and thermal sensation (TS,

13 0=unbearably cold to 8=unbearably hot) [35] were noted at the end of each stage. The following

14 physiological responses were calculated; running speeds at blood lactate concentrations of 2 and 4

15 mmol.l^{-1}, running economy (RE), $\dot{V}O_{2max}$ and velocity at $\dot{V}O_{2max}$ (v$\dot{V}O_{2max}$) as per James et al. [29].

16 Derivative calculations included mean T_{SKIN} [33], Physiological Strain Index (PSI) [36] and change in plasma

17 volume [37]. During the 5 km time trial, HR, T_{CORE}, T_{SKIN}, RPE and TS were recorded every km.

18 **Statistical analyses**

19   All outcome variables were assessed for normality and sphericity prior to further analysis. Where

20 assumptions of ANOVA were not met, non-parametric statistics were adopted. Exercise data from

21 both the GXTs and TTs were analysed using two-way, repeated measures ANOVA (Trial*Time) where

22 data comprised repeated time points, with post hoc Bonferroni adjusted pairwise comparisons used

23 where significant main or interaction effects occurred. During the time trials, all average, finishing and

24 delta change data from physiological and performance variables were analysed with One-way

25 repeated measures ANOVA. Where the use of repeated measures ANOVA was precluded through the

Combining heat acclimation and precooling for running in the heat.

1   violation of parametric assumptions, such as TT performance, Friedman's ANOVA, with Wilcoxon

2   follow up tests, were used to analyse these data. Singular data, that did not have repeated measures

3   within the GXT, were analysed using Paired samples t-tests. Effect sizes for main effects and

4   interaction effects are presented as partial eta squared (partial $\eta 2$), differences between related

5   samples were evaluated through Cohen's d_{av} (d_{av}) [38]. Data were analysed using SPSS (Version 21, SPSS

6   Inc., USA) with statistical significance set at $p<0.05$ and data presented as means and standard

7   deviation (±SD).

8   **RESULTS**

9   **Heat acclimation training**

10   Mean exercising time during STHA training was 39 (6) min, completed at a relative exercise

11   intensity of 2.7 (0.3) $W.kg^{-1}$ (201 [33] W). The training environmental conditions (36.6 [0.8]°C, 59 [9]%

12   RH) elicited a mean peak session HR of 176 (9) $b.min^{-1}$ and average session T_{CORE} of 38.5 (0.2)°C. The

13   mean time T_{CORE} exceeded 38.5°C during each session was 63 (5) min, with an average peak session

14   T_{CORE} of 39.1 (0.2)°C. Mean sweat rate was 1.5 (0.5) $L.hr^{-1}$, equating to 3.2 (1.1)% of body mass.

15   **Graded exercise tests**

16   Statistically significant reductions in resting (-0.15°C, $p=0.01$, $d_{av}=0.45$) and exercising T_{CORE} (-

17   0.21°C, $p=0.04$, $d_{av}=0.54$) were observed, alongside a reduced exercising (-3 $b.min^{-1}$, $p=0.02$, $d_{av}=0.26$),

18   but not resting HR (-2 $b.min^{-1}$, $p=0.115$, $d_{av}=0.36$). Total sweat loss did not change following STHA (Pre

19   1.35 [0.3] L, Post 1.39 [0.39] L, $p= 0.503$, $d_{av}=0.13$), but occurred alongside a smaller change in T_{CORE} (Δ

20   Pre 1.26 [0.27] °C, Δ Post 1.00 [0.28] °C, $p=0.006$, $d_{av}=0.91$) indicating increased sudomotor sensitivity.

21   A 5.7% increase ($p=0.03$, $d_{av}=1.06$) in blood plasma volume was also observed. No changes were

22   observed in mean RPE ($p=0.342$) or TS ($p=0.262$), although there was a reduced change in thermal

23   sensation ($p=0.04$, $d_{av}=0.86$). For complete STHA results please see James et al. [22].

Combining heat acclimation and precooling for running in the heat.

1   The GXT also revealed an enhanced $\dot{V}O_{2max}$ following STHA (+4.0 [2.2] mL.kg^{-1}.min^{-1}, +7.3 [4.0]%,

2   p=0.003, d_{av}=0.47). A reduced respiratory exchange ratio (-0.08, p=0.03, d_{av}=0.59) during exercise is

3   commensurate with improvements observed in both the LT (+0.4 [0.6] k.hr^{-1}, +4.0 [6.0]%, p=0.073**,**

4   d_{av}=0.24) and LTP (+0.3 [0.4] k.hr^{-1}, +2.5 [2.9]%, p=0.022, d_{av}=0.20). No statistical difference was

5   observed in v$\dot{V}O_{2max}$ (p=0.144, d_{av}=0.24), although the mean difference of 0.5 (0.8) k.hr^{-1} (3.5 [5.3]%)

6   is potentially meaningful given our laboratory typical error of 2.9% for this measure in a similarly

7   trained cohort. Finally, RE worsened, with a greater amount of oxygen consumed per kilometre

8   following heat acclimation (+7.3 [7.3] mL.kg^{-1}.km^{-1}, 3.5 [3.5]%, p=0.017, d_{av}=0.59).

9   **Time trial performances**

10   Environmental conditions (WBGT) did not differ between trials; CON=27.4 (0.7)°C, PC=26.9 (0.5)°C,

11   HA=27.5 (0.9)°C, HA+PC=27.0 (0.8)°C (p=0.246, partial η2=0.156). Self-reported motivation, muscle

12   soreness and stress responses did not differ between trials for the female participant or for the group

13   as a whole (p>0.05). Friedman's ANOVA revealed a difference in TT performance between trials

14   (p=0.001). However, Wilcoxon tests with Bonferroni correction (whereby significance = p<0.008), only

15   indicated a significant difference between the control trial and HA+PC. Group mean (±SD)

16   performance times were; CON 1476 (173)s, PC 1421 (146)s, HA 1378 (116)s and HA+PC 1373 (121)s.

17   Relative to control, a large mean improvement was observed in HA and HA+PC, with a modest

18   improvement following PC (Table 1), although neither reached statistical significance. Compared with

19   CON, nine participants ran faster in HA, whilst eight ran faster in HA+PC and PC trials. There was no

20   observable difference in running performance between HA and HA+PC trial, whilst the observed effect

21   sizes and mean difference indicate modest improvements in HA and HA+PC compared with PC (Table

22   1). In HA+PC, eight participants ran faster than in PC, with six participants performing better in HA

23   than PC. Figure 2 displays the kilometre splits for each trial.

1 Table 1: Relative difference in 5 km time trial performance between trials. *Corrected statistical significance level for Wilcoxon signed-rank test post hoc

2 $p<0.008$. Previously established typical error following 5 days high intensity normothermic training = 16 s, 1.2%. Data are; mean change (s), percentage change

3 (%), statistical significance (p) and effect size (d) with 95% confidence intervals (CI). +/- represents the performance difference (s) relative to the trial in that

4 row.

	Time trial time	Control	Precooling	Heat acclimation	Heat acclimation + precooling
Control	1476 (173) s	-	+55 s (3.7%) (p=0.039, d=0.34) 95% CI = -0.59, 1.27	+98 s (6.6%) (p=0.004*, d=0.68) 95% CI =-0.27, 1.63	+103 s (7.0%) (p=0.012, d=0.70) 95% CI =-0.25, 1.65
Precooling	1421 (146) s	-55 s (3.7%) (p=0.039, d=0.34) 95% CI = -0.59, 1.27	-	+43 s (3.0%) (p=0.098, d=0.33) 95% CI =-0.60, 1.26	+48 s (3.4%) (p=0.023, d=0.36) 95% CI =-0.57, 1.29
Heat acclimation	1378 (116) s	-98 s (6.6%) (p=0.004*, d=0.68) 95% CI =-0.27, 1.63	-43 s (3.0%) (p=0.098, d=0.33) 95% CI =-0.60, 1.26	-	+5 s (0.4%) (p=0.590, d=0.04) 95% CI =-0.88, 0.96
Heat acclimation + precooling	1373 (121) s	-103 s (7.0%) (p=0.012, d=0.70) 95% CI =-0.25, 1.65	-48 s (3.4%) (p=0.023, d=0.36) 95% CI =-0.57, 1.29	-5 s (0.4%) (p=0.590, d=0.04) 95% CI =-0.88, 0.96	-

5
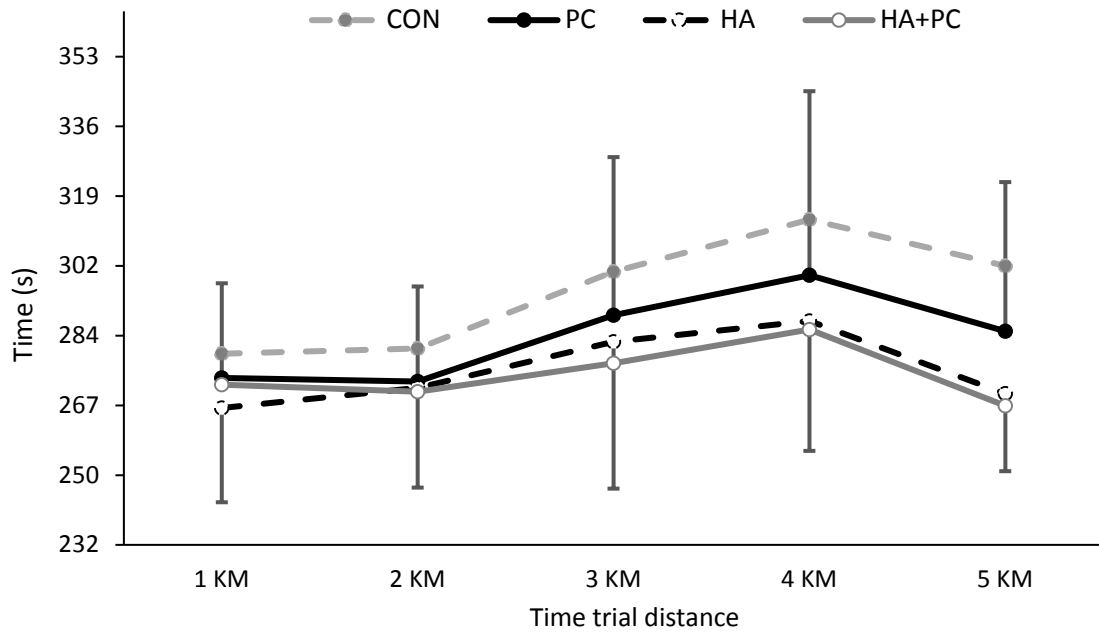
Figure 2: Mean (±SD) kilometre split times during the 5 km time trial. Error bars represent one standard deviation. Error bars for control (CON) and heat acclimation + precooling (HA+PC) trials are omitted for clarity, but homogeneity of variance was present.

Following 20 min cooling there was no change in T_{CORE} (p=0.219, partial η2=0.165). Therefore, starting T_{CORE} was not different between trials (p=0.697, partial η2=0.075); CON 37.12 (0.22)°C, PC 37.07 (0.30)°C, HA 37.07 (0.23)°C and 37.2 (0.22)°C during HA+PC. Large reductions in T_{SKIN} (p<0.001, partial η2=0.906) were observed across the cooling period in the trials containing precooling (-6.9 [2.7]°C PC; -6.8 [1.5]°C HA+PC), whilst T_{SKIN} was unchanged in non-precooling trials (CON +0.87 [0.50]°C; HA +0.58 [0.58]°C). Therefore, starting T_{SKIN} in PC (26.9 [2.8]°C) and HA+PC (26.4 [1.9]°C) were lower (p<0.001, partial η2=0.900) than in non-precooled trials (34.3 [0.7]°C CON, 34.0 [0.4]°C HA). This coincided with a reduced starting thermal sensation (p=0.002, partial η2=0.907) in PC (2.2 [0.8]) and HA+PC (2.4 [0.8]), compared with CON (4.4 [0.6] and HA (3.7 [1.5]). Finally, a greater core:skin gradient (p<0.001, partial η2=0.896) was observed in PC (9.6 [2.6]°C) and HA+PC (10.5 [1.7]°C), compared with CON (2.7 [0.6]°C) and HA (3.2 [0.5]°C). Plots of thermoregulatory variables during all trials are shown in Figure 3.

Combining heat acclimation and precooling for running in the heat.

1   During the TTs, there was no difference in mean T_{CORE} between conditions (p=0.117, partial

2   η2=0.273), however the change (Δ) in T_{CORE} was different (p=0.044, partial η2=0.776) as shown in Figure

3   3. Finishing T_{CORE} differed between conditions (p=0.025, partial η2=0.396), with CON the warmest

4   (39.34 [0.30]°C), followed by PC (39.24 [0.51]°C), HA (39.16 [0.44]°C) and the lowest finishing T_{CORE} in

5   HA+PC (38.96 [0.43]°C).

6   The differences observed in starting T_{SKIN} continued during the respective TTs (p=0.010, partial

7   η2=0.369). Mean T_{SKIN} was highest during CON (35.3 [1.2]°C), followed by HA (34.6 [0.7]°C), PC (34.6

8   [1.2]°C) and the lowest was in HA+PC (34.1 [0.9]°C) as shown in Figure 3. However, a statistical

9   difference was only observed between CON and PC (p=0.029, d=0.58). A difference in finishing T_{SKIN}

10   was also apparent (p=0.037, partial η2=0.293), although only between CON and HA (p=0.026, d=0.48).

11   Finishing T_{SKIN} for each trial was; CON 35.1 (1.2)°C, PC 35.7 (1.2)°C, HA 34.6 (1.0)°C and HA+PC 34.9

12   (1.0)°C.

13   The mean core:skin gradient was also different between conditions (p=0.005, partial η2=0.504), as

14   shown in Figure 3. The largest gradient was observed in HA+PC (4.2 [1.2]°C), followed by HA (3.7

15   [0.8]°C), PC (3.6 [1.0]°C) and CON (2.9 [0.9]°C, with statistical differences between CON and HA+PC

16   (p=0.034, d=1.24). There were different finishing core:skin gradients (p=0.028, partial η2=0.388), with

17   the largest observed in HA (4.3 [1.1]°C) and HA+PC (4.2 [1.2]°C), followed by PC (3.7 [1.0]°C) and CON

18   (3.4 [1.0]°C).
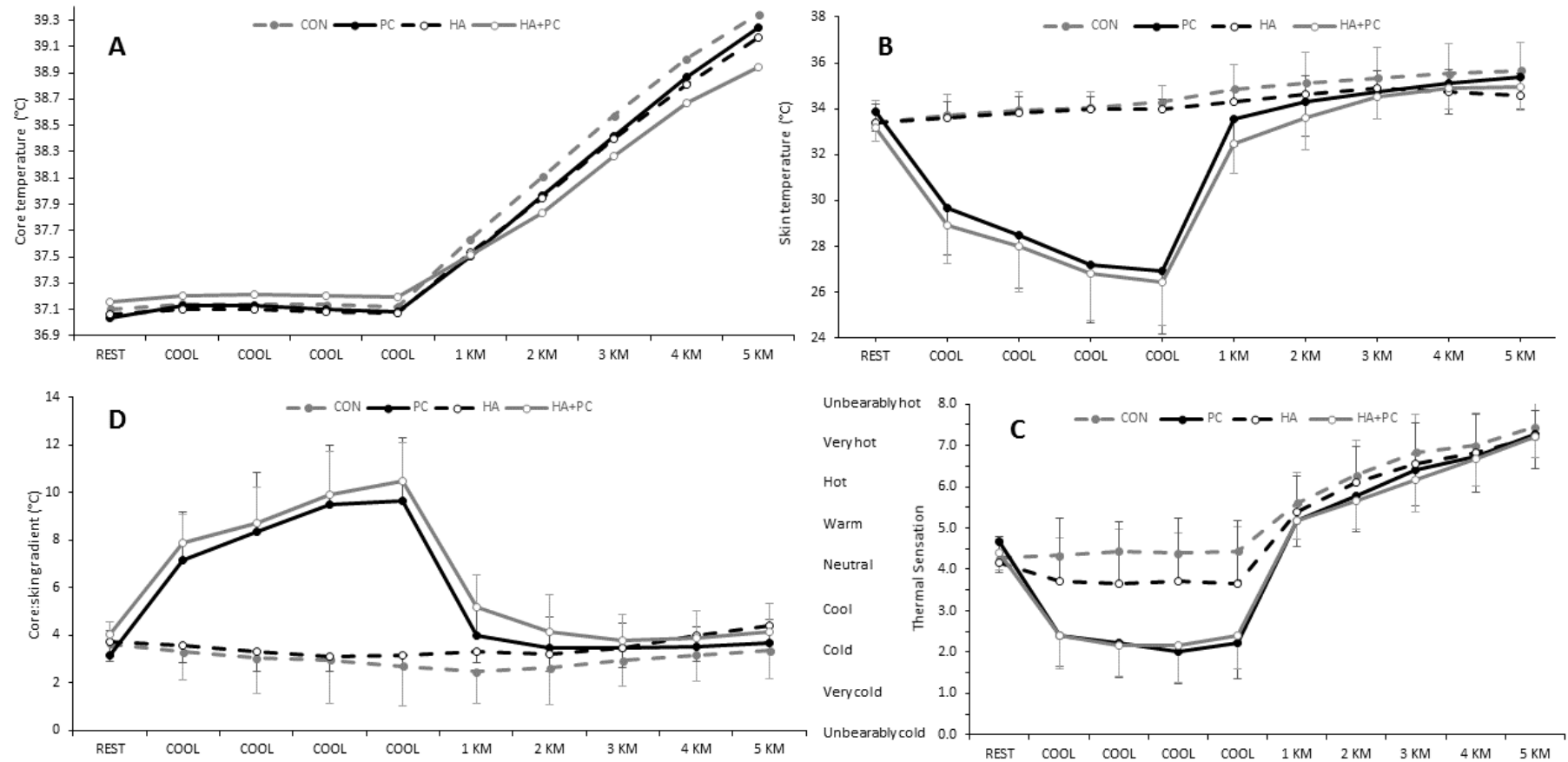
1

2　Figure 3: Clockwise from top left: Mean (±SD) core temperature (A), skin temperature (B), thermal sensation (C) and core:skin gradient (D) during rest, cooling

3　and exercise phases of the time trial protocol. Each increment represents 5 min during rest and cooling phases. The time trial began 15 min after cooling

4　finished. Error bars represent one standard deviation, with core temperature error bars omitted for clarity. Participants completed additional rest in CON and

5　HA trials during the 'cooling' phase.

1   No differences were observed in the mean TS (p=0.066, partial η2=0.255) or RPE (p=0.213, partial

2   η2=0.168) between conditions. Neither mean HR (p=0.252, partial η2=0.154) or finishing HR (p=0.734,

3   partial η2=0.051), differed between conditions. Similarly, mean HR as a percentage of maximum HR

4   (%HRmax) was not different between conditions (p=0.089, partial η2=0.234), as shown in Figure 4. The

5   mean %HRmax for each trial was; CON 93.4 (3.8)%, PC 94.6 (4.9)%, HA 93.3 (3.8)% and HA+PC 91.6

6   (3.1)%. Sweat loss was different between trials (p=0.008, partial η2=0.386), with the largest fluid loss

7   in HA (2.5 [0.5] l.hr^{-1}), compared with CON (2.2 [0.8] l.hr^{-1}), PC (1.7 [0.5] l.hr^{-1}) and HA+PC (2.3 [0.6]

8   l.hr^{-1}). Pairwise comparisons revealed a difference between PC and HA (p=0.006, d=1.50), but not

9   other conditions.
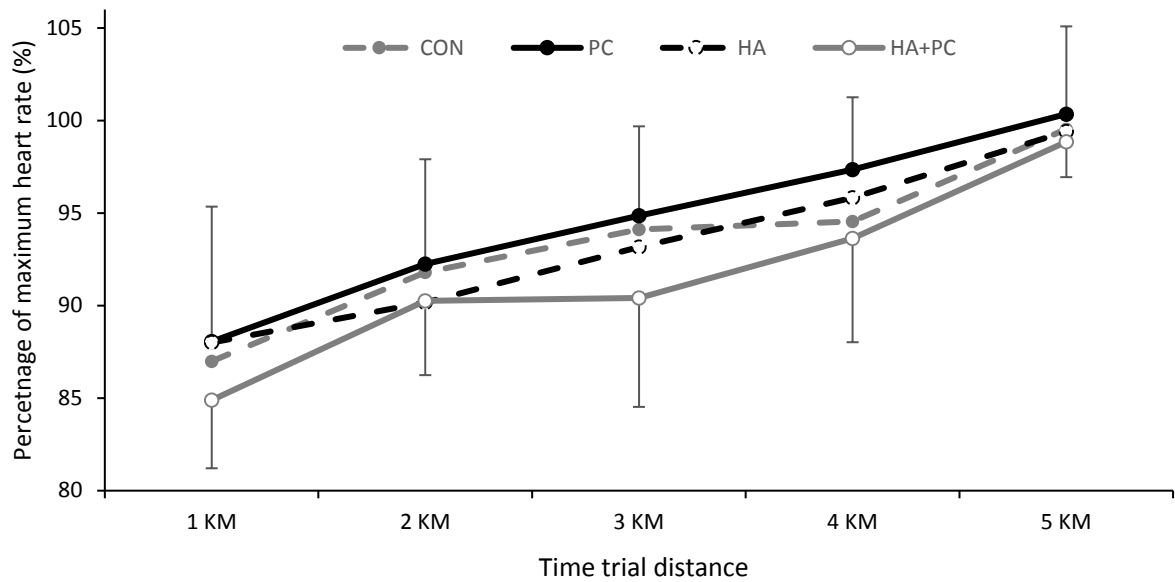
10

11   Figure 4: Mean (±SD) percentage of maximum heart rate maintained throughout each trial. Error bars

12   represent one standard deviation. Error bars for control and heat acclimation trials are omitted for

13   clarity, but homogeneity of variance was present.

14

Combining heat acclimation and precooling for running in the heat.

1 DISCUSSION

2   Our primary aim was to assess the efficacy of combining precooling and heat acclimation for

3 improving endurance running performance in the heat. Our data reaffirm previous observations, with

4 precooling offering no further benefit to performance in the acclimated individual, but demonstrate

5 modest alleviation of physiological strain. The second aim was to directly compare the ergogenic

6 potential of precooling and heat acclimation. Despite the lack of a statistical difference, these data

7 indicate heat acclimation improves endurance running performance further than precooling.

8 **Combined heat acclimation and precooling**

9   In spite of the theoretical potential to improve running performance further by adding precooling,

10 we did not observe a performance improvement in HA+PC above that of HA. The only prior study

11 investigating HA+PC on endurance exercise, highlighted a potentially meaningful greater self-selected

12 exercise intensity during the first half of the cycling time trial, alongside reduced thermal sensation [17].

13 However, the faster pace was not sustained, reducing alongside the dissipation of PC effects, with a

14 comparable trend in the precooled trials completed prior to the heat acclimatisation camp. Our data,

15 implementing a more potent cooling strategy in HA+PC, afforded greater differences in T_{CORE}, T_{SKIN},

16 core:skin gradient and thermal sensation during the first half of the trial (Figure 3), but did not alter

17 the initial pace. The reasons for this are unclear, but speculatively, may represent a different, and

18 ultimately sub-optimal, pacing strategy being adopted in HA+PC.

19   Recent evidence indicates athletes target a more even pacing profile with familiarisation in the

20 heat [39] and as shown in Figure 2, HA+PC displays the most even profile. It appears this was sub-optimal

21 following HA+PC, given the transient benefit that precooling affords, an interpretation supported by

22 a slightly lower %HRmax during HA+PC until 4 km into the trial (Figure 4). This indicates participants

23 exercised at a lower relative intensity in HA+PC, despite relative intensity normally being maintained

24 across individuals for a given event [40]. Therefore, both the mediated physiological and

25 thermoregulatory strain afforded by HA+PC during the first half of the trial may not have been

17

Combining heat acclimation and precooling for running in the heat.

1 exploited, as individuals targeted an even pace. These observations are supported by participant

2 feedback, indicating pacing may have been incorrect, either under/overestimating the effect of

3 HA+PC, resulting in them beginning at too high or too low a pace. We therefore recommend further

4 familiarisation is necessary when combining interventions. Future research should consider whether

5 familiarisation to exercise in the heat is influenced by racing experience or performance standard and

6 thus specific to the population used in a study.

7 Previous studies have suggested cardiovascular and thermoregulatory adaptations from HA may

8 reduce the ergogenic effects of PC by influencing the same mechanisms, such as the enlarged core:skin

9 gradient and reduced cardiovascular strain, creating an insensitivity or 'ceiling effect' [14,17]. However,

10 when an aggressive precooling technique is adopted and heat strain remains severe, these data would

11 contend otherwise, evidencing small beneficial changes, notably in %HRmax and T_{SKIN}. Therefore,

12 further familiarisation with HA+PC appears necessary to ensure pacing is optimised and future

13 research should investigate this across a range of standards of athletes, including 5 km distance

14 specialists.

15

16 **Comparison of heat acclimation and precooling**

17 A secondary aim was to directly compare the effect of acute and chronic interventions on

18 endurance running performance. Participants ran 43 s (3%) faster following HA than PC, which exceeds

19 our typical error, established during pilot testing, of 16 s (1.2%). In-turn, PC afforded a 55 s (3.7%)

20 improvement over CON, with eight participants improving more than our typical error. In HA,

21 compared with CON, six participants improved more than the typical error, with a mean improvement

22 of 98 s (6.6%), which was the only statistically significant difference. That no other comparisons were

23 statistically different likely reflects a disparity in running performance within this cohort, as well as the

24 adoption of a more conservative non-parametric statistical test, with both the mean differences and

25 effect sizes (Table 1) indicative of meaningful changes between conditions. Indeed, six participants

18

Combining heat acclimation and precooling for running in the heat.

1   ran faster in HA than PC, with five improving more than the typical error. Elapsed time was similar

2   between HA and PC at 2 km (PC; 547 [46] s, HA; 538 [45] s), before PC demonstrated a greater

3   reduction in running speed between 2-4 km (elapsed time at 4 km PC; 1135 [111] s, HA; 1108 [106] s).

4   As shown in Figure 3, this reduction in running speed during PC coincides with the dissipation of a

5   lower T_{SKIN} and core:skin gradient, relative to HA. It is possible the trial order may have contributed to

6   the flatter pacing profile in HA, as PC was not randomised with HA, and both repeated trials [41] and

7   familiarisation to the heat [39] may result in a flatter pacing profile. Therefore, it is more likely that the

8   greater reduction in running speed in PC reflects greater heat strain, given the aforementioned

9   dissipation of both a reduced T_{SKIN} and core:skin ratio. Concomitantly, this may result in a greater

10   progressive reduction in $\dot{V}O_{2max}$, necessitating a reduced running speed to maintain relative intensity

11   during PC.

12   The reduction in maximum aerobic capacity has been suggested to be the most plausible

13   explanation for the decline in endurance performance under heat stress [42], whilst the relative intensity

14   that an event is completed at has been shown to be maintained across both hot, cold and hypoxic

15   conditions [41,43]. Given the transient nature of the intervention, precooling does not provide prolonged,

16   uniform alleviation of cardiovascular and thermoregulatory strain, as shown by the ineffectiveness of

17   precooling on $\dot{V}O_{2max}$ after approximately 30 min of exercise [8]. Conversely, meaningful improvements

18   in $\dot{V}O_{2max}$ in the heat were observed following HA, which may present for 5-14 days, depending on the

19   HA protocol adopted, in accordance with HA decay [44,45] and would facilitate a greater maintained

20   running speed, despite the inevitable progressive decline in $\dot{V}O_{2max}$. Enhanced $\dot{V}O_{2max}$ (~7%) following

21   HA is thought to arise primarily through an expanded plasma volume [6], whilst endurance performance

22   may also benefit from a slowed progressive decline in $\dot{V}O_{2max}$ during exercise, due to increased heat

23   dissipation. A lower T_{SKIN} better maintains the core:skin gradient, thereby mediating cutaneous blood

24   flow demands and preserving stroke volume and $\dot{V}O_{2max}$ [46], as well as delaying exercise termination

25   under heat stress [47].

Combining heat acclimation and precooling for running in the heat.

1   Alongside improved maintenance of a runner's aerobic capacity in the heat, HA reduced the

2   change in perceived thermal strain during the GXT and afforded reduced T_{SKIN} relative to PC during the

3   second half of the TT (Figure 3), which is pertinent given elevated T_{SKIN} and thermal discomfort are

4   associated with the voluntary reduction of exercise intensity in the heat [13,48]. Although, Ely et al. [42]

5   suggest these effects may be subsidiary to the decrement in $\dot{V}O_{2max}$ and subsequent increase in relative

6   intensity at a fixed running speed, given the magnitude of $\dot{V}O_{2max}$ impairment.

7   Relative intensity and perceived thermal strain alone cannot fully explain the differences between

8   HA and PC, given the different pace after one kilometre. Speculatively, this could reflect a lower

9   training status of the current cohort of runners, who began trials with a predetermined even-paced

10   strategy, in comparison to the highly experienced cyclists in the study of Racinais et al. [41] who

11   maintained a fixed relative intensity (%$\dot{V}O_{2max}$) from the start of the trial. Alternatively, naivety of the

12   optimal pacing following precooling would also seem plausible. In HA+PC, the marked reduction in

13   T_{SKIN} that persists through the first half of the trial, differs from the afferent feedback participants are

14   accustomed to, that determines self-selected running speed in the heat [13]. Indeed, anecdotally,

15   participants highlighted ambiguity about how to maximise performance in PC, reinforcing the notion

16   that pacing must be practiced, through repeated familiarisation, in advance of adopting PC in

17   competition. Therefore, these data would appear to be the first to demonstrate a marked advantage

18   from STHA over acute precooling in club runners, running in the heat.

19   Despite the sub-elite training status of this cohort, our design controls for an order effect because

20   the number and scheduling of experimental trials was in keeping with their weekly training load,

21   meaning familiarisations and pre/post trials are unlikely to have elicited changes in training status.

22   Furthermore, participants also completed cycling training, rather than running, which helps to control

23   for any mode-specific adaptations biasing our conclusions. Finally, whilst daily HA provides an

24   increased training volume, this is an inherent part of this intervention. Passive heat acclimation

25   protocols were not selected because we wanted to compare what we feel to be an optimal approach

Combining heat acclimation and precooling for running in the heat.

1   i.e. higher intensity exercise & a controlled hyperthermia model, as supported by recent literature

2   [23,24,27,49,50].

3   Despite the reduced performance compared with HA, these data reaffirm the potential for mixed

4   methods, precooling to benefit endurance performance in the heat when HA is not possible. Whilst

5   the use of external precooling for endurance performance is well supported [10,11], this has not

6   previously been assessed during free-paced endurance exercise. As per previous research that have

7   used this technique [8,9,12], PC did not elicit a reduction in T_{CORE} during the cooling phase. Similarly, an

8   'after-drop' was not observed, whereby vasoconstriction dissipates and warm blood is subsequently

9   cooled in the periphery [51], which is likely a result of the significant and immediate metabolic heat

10   production during treadmill running. A reduced rate of T_{CORE} increase may be inferred, given similar

11   response to CON, but at higher running speeds.

12   It should be acknowledged that the lack of air-flow, as might be experienced outdoors, may over-

13   estimate the magnitude of the reported PC effect [52], although the influence will be less severe than in

14   cycling due to the reduced air velocity during running. Another potential limitation is the failure to

15   counterbalance the order of the pre and post training time trials, therefore the magnitude of

16   improvement may be exaggerated. However, when compared against the typical error of 16 s (1.2%),

17   the reported improvements all appear to represent true differences.

18   **Practical applications**

19   These results suggest athletes and coaches should prioritise a HA strategy where possible prior to

20   endurance exercise in the heat. When this is not possible, a mixed methods precooling strategy, that

21   cools a large surface area of skin, would appear to remain beneficial, although time should be taken

22   to familiarise with pacing strategies. Combining HA and PC appears to elicit a better maintenance of

23   the core:skin gradient, but this did not transfer into improved 5km time trial performance. Therefore,

Combining heat acclimation and precooling for running in the heat.

1   researchers, practitioners and coaches should consider familiarising individuals with HA+PC to ensure

2   pacing strategies maximise the alleviation of physiological strain.

Combining heat acclimation and precooling for running in the heat.

REFERENCES

1. Racinais S, Alonso J-M, Coutts AJ, Flouris AD, Girard O, Gonzalez-Alonso J, Hausswirth C, Jay O, Lee JKW, Mitchell N, Nassis GP, Nybo L, Pluim BM, Roelands B, Sawka MN, Wingo JE, Périard JD. Consensus recommendations on training and competing in the heat. *Scand J Med Sci Sports*. 2015;25:6–19.

2. Garrett AT, Rehrer NJ, Patterson MJ. Induction and decay of short-term heat acclimation in moderately and highly trained athletes. *Sport Med*. 2011;41:757–71.

3. 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;25:20–38.

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. *Sport Med*. 2015;45:303–11.

5. Gonzalez-Alonso J, Crandall CG, Johnson JM. The cardiovascular challenge of exercising in the heat. *J Physiol*. 2008;586:45–53.

6. Lorenzo S, Halliwill JR, Sawka MN, Minson CT. Heat acclimation improves exercise performance. *J Appl Physiol*. 2010;109:1140–7.

7. Sawka MN, Young AJ, Cadarette BS, Levine L, Pandolf KB. Influence of heat stress and acclimation on maximal aerobic power. *Eur J Appl Physiol Occup Physiol*. 1985;53:294–8.

8. James CA, Richardson AJ, Watt PW, Gibson OR, Maxwell NS. Physiological responses to incremental exercise in the heat following internal and external precooling. *Scand J Med Sci Sports*. 2015;25:190–199.

9. Minett GM, Duffield R, Marino FE, Portus M. Volume-dependent response of precooling for intermittent-sprint exercise in the heat. *Med Sci Sports Exerc*. 2011;43:1760–9.

10. Bongers CCWG, Thijssen DHJ, Veltmeijer MTW, Hopman MTE, Eijsvogels TMH. Precooling and percooling (cooling during exercise) both improve performance in the heat: a meta-analytical review. *Br J Sports Med*. 2015;49:377–384.

11. Tyler CJ, Sunderland C, Cheung SS. The effect of cooling prior to and during exercise on exercise performance and capacity in the heat: a meta-analysis. *Br J Sports Med*. 2015;49:7–13.

12. Duffield R, Steinbacher G, Fairchild TJ. The use of mixed-method, part-body pre-cooling procedures for team-sport athletes training in the heat. *J Strength Cond Res*. 2009;23:2524–2532.

13. Flouris AD, Schlader ZJ. Human behavioral thermoregulation during exercise in the heat. *Scand J Med Sci Sports*. 2015;25 Suppl 1:52–64.

14. Castle PC, Mackenzie RW, Maxwell NS, Webborn ADJ, Watt PW. Heat acclimation improves intermittent sprinting in the heat but additional pre-cooling offers no further ergogenic effect. *J Sports Sci*. 2011;29:1125–34.

15. Brade C, Dawson BT, Wallman K. Effect of precooling and acclimation on repeat-sprint performance in heat. *J Sports Sci*. 2012;31:779–86.

16. Galloway SD, Maughan RJ. Effects of ambient temperature on the capacity to perform prolonged cycle exercise in man. *Med Sci Sports Exerc*. 1997;29:1240–1249.

17. Schmit C, Le Meur Y, Duffield R, Robach P, Oussedik N, Coutts AJ, Hausswirth C. Heat-acclimatization and pre-cooling: a further boost for endurance performance? *Scand J Med Sci Sports*. 2015;

18. Nielsen B. Regulation of Body Temperature and Heat Dissipation at Different Levels of Energy-and Heat Production in Man. *Acta Physiol Scand*. 1966;68:215–227.

19. Millet GP, Vleck VE, Bentley DJ. Physiological differences between cycling and running: lessons from triathletes. *Sport Med*. 2009;39:179–206.

20. Chan KOW, Wong SHS, Chen YJ. Effects of a hot environment on simulated cycling and running performance in triathletes. *J Sports Med Phys Fitness*. 2008;48:149–157.

21. Reilly T, Waterhouse J. Circadian aspects of body temperature regulation in exercise. *J Therm Biol*. 2009;34:161–170.

22. James CA, Richardson AJ, Watt PW, Willmott AGB, Gibson OR, Maxwell NS. Short term heat acclimation improves the determinants of endurance performance and 5,000 m running performance in the heat. *Appl Physiol Nutr Metab*. 2016;apnm-2016-0349.

23. Mee JA, Gibson OR, Doust JH, Maxwell NS. A comparison of males and females' temporal patterning to short- and long-term heat acclimation. *Scand J Med Sci Sports*. 2015;25:250–258.

24. Gibson OR, Mee JA, Tuttle JA, Taylor L, Watt PW, Maxwell NS. Isothermic and fixed intensity heat acclimation methods induce similar heat adaptation following short and long-term timescales. *J Therm*

Combining heat acclimation and precooling for running in the heat.

Biol. 2015;49–50:55–65.

25. Gibson OR, Willmott AGB, James C, Hayes M, Maxwell NS. Power relative to body mass best predicts change in core temperature during exercise-heat stress. *J Strength Cond Res*. 2016;

26. 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;460:467–485.

27. Garrett AT, Goosens NG, Rehrer NJG, Patterson MJ, Harrison J, Sammut I, Cotter JD, Patterson J. Short-term heat acclimation is effective and may be enhanced rather than impaired by dehydration. *Am J Hum Biol*. 2014;26:311–20.

28. Jones AM. Middle and Long distance running. In: Sport and Exercise Physiology Testing Guidelines: Volume I – Sport Testing: The British Association of Sport and Exercise Sciences Guide. Routledge; 2006. p. 384.

29. James CA, Willmott AGB, Richardson AJ, Watt PW, Maxwell NS. Ischaemic preconditioning does not alter the determinants of endurance running performance in the heat. *Eur J Appl Physiol*. 2016;1–11.

30. Stannard AB, Brandenburg JP, Pitney WA, Lukaszuk JM. Effects of wearing a cooling vest during the warm-up on 10-km run performance. *J Strength Cond Res*. 2011;25:2018–2024.

31. Sawka MN, Burke LM, Eichner ER, Maughan RJ, Montain SJ, Stachenfeld NS. American College of Sports Medicine position stand. Exercise and fluid replacement. *Med Sci Sports Exerc*. 2007;39:377–90.

32. James CA, Richardson AJ, Watt PW, Maxwell NS. Reliability and validity of skin temperature measurement by telemetry thermistors and a thermal camera during exercise in the heat. *J Therm Biol*. 2014;45:141–149.

33. Ramanathan NL. A New Weighting System for Mean Surface Temperature of the Human Body. *J Appl Physiol*. 1964;19:531–3.

34. Borg G. Borg's perceived exertion and pain scales. Champaign, Illinois: Human Kinetics; 1998.

35. Gagge A, Stolwijk J, Saltin B. Comfort and thermal sensations and associated physiological responses during exercise at various ambient temperatures. *Environ Res*. 1969;229:209–229.

36. Moran D, Shitzer A, Pandolf K. A physiological strain index to evaluate heat stress. *Am J Physiol Regul Integr Comp Physiol*. 1998;277:129–134.

37. Dill DB, Costill DL. Calculation of percentage changes in volumes of blood, plasma, and red cells in dehydration. *J Appl Physiol.* 1974;37:247–248.

38. Lakens D. Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. *Front Psychol*. 2013;4:863.

39. Schmit C, Duffield R, Hausswirth C, Coutts AJ, Le Meur Y. Pacing Adjustments Associated With Familiarisation: Heat vs. Temperate Environments. *Int J Sports Physiol Perform*. 2015;

40. Leger L, Mercier D, Gauvin L. The relationship between %VO2max and running performance time. In: Landers DM, editor. Sport and Elite Performers. Champaign, Illinois: Human Kinetics Publishers; 1986. p. 113–120.

41. 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;47:601–6.

42. Ely BR, Ely MR, Cheuvront SN, Kenefick RW, Degroot DW, Montain SJ. Evidence against a 40 degrees C core temperature threshold for fatigue in humans. *J Appl Physiol*. 2009;107:1519–25.

43. Periard JD, Racinais S. Performance and pacing during cycle exercise in hyperthermic and hypoxic conditions. *Med Sci Sports Exerc*. 2016;48:845–853.

44. Garrett AT, Goosens NG, Rehrer NJ, Rehrer NG, Patterson MJ, Cotter JD. Induction and decay of short-term heat acclimation. *Eur J Appl Physiol*. 2009;107:659–70.

45. Poirier MP, Gagnon D, Friesen BJ, Hardcastle SG, Kenny GP. Whole-body heat exchange during heat acclimation and its decay. *Med Sci Sports Exerc*. 2015;47:390–400.

46. Périard JD, Cramer MN, Chapman PG, Caillaud C, Thompson MW. Cardiovascular strain impairs prolonged self-paced exercise in the heat. *Exp Physiol*. 2011;96:134–44.

47. Cuddy JS, Hailes WS, Ruby BC. A reduced core to skin temperature gradient, not a critical core temperature, affects aerobic capacity in the heat. *J Therm Biol*. 2014;43:7–12.

48. Schlader ZJ, Simmons SE, Stannard SR, Mündel T. Skin temperature as a thermal controller of exercise intensity. *Eur J Appl Physiol*. 2011;111:1631–9.

49. Gibson OR, Turner G, Tuttle JA, Taylor L, Watt PW, Maxwell NS. Heat Acclimation attenuates physiological strain and the Hsp72, but not Hsp90α mRNA response to acute normobaric hypoxia. *J Appl Physiol*. 2015;119:jap.00332.2015.

50. Neal RA, Corbett J, Massey HC, Tipton MJ. Effect of short-term heat acclimation with permissive

Combining heat acclimation and precooling for running in the heat.

1   dehydration on thermoregulation and temperate exercise performance. *Scand J Med Sci Sports*.
2   2015;Epub ahead of print.
3 51. Webb P. Afterdrop of body temperature during rewarming: an alternative explanation. *J Appl Physiol*.
4   1986;60:385–390.
5 52. Morrison SA, Cheung SS, Cotter JD. Importance of airflow for physiologic and ergogenic effects of
6   precooling. *J Athl Train*. 2014;49:632–9.
7