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ORIGINAL ARTICLE

Evaluation of an off-feet heat response test for elite rugby sevens athletes

Évaluation d'un test de réponse à la chaleur à faible charge des membres inférieurs pour les joueurs élites de rugby à 7

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Summary A heat response test (HRT) assesses adaptations to heat stress and athlete readiness to perform in hot conditions. However, testing is often not sport-specific, and is challenging to incorporate into elite team-sports schedules due to competing training priorities. Seven non-heat acclimated elite rugby sevens athletes (25 ± 3 years; 95.3 ± 6.5 kg; 190 ± 3 cm) undertook two rugby sevens specific running tests in ambient (20 °C, 50% rH; RUN:AMB), and hot (35 °C, 80% rH; RUN:HOT) conditions, along with a heart rate (HR) matched cycling-based HRT (CYCLE:HOT). Physiological and perceptual variables were monitored throughout each test. Mean tympanic temperature (T_{Tymp}), HR, thermal sensation, rate of perceived exertion, and sweat loss significantly increased, while thermal discomfort and performance decreased in RUN:HOT compared with RUN:AMB, (all $d > 1.40$; $p < 0.05$). Significant reductions in mean T_{Tymp} and HR were evident in CYCLE:HOT compared with RUN:HOT (both $d > 1.10$; $p < 0.05$), whereas there were no clear differences in any perceptual variables. Mean peak T_{Tymp} was 39.5 ± 0.5 °C in RUN:HOT and 38.8 ± 0.4 °C CYCLE:HOT, respectively. Acute heat stress is detrimental to performance in non-heat acclimated elite rugby sevens athletes. High-intensity cycling in the heat can replicate the perceptual (but not the physiological) stress associated with high-intensity

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running in the heat. Cycling-based HRT could be used to avoid additional mechanical load associated with running-based heat testing.

MOTS CLÉS
Sports collectifs ;
Tests ;
Sprints répétés ;
Course ;
Cyclisme

Résumé Un test de réponse à la chaleur (TRC) évalue les adaptations au stress thermique et la préparation de l'athlète à performer dans des conditions climatiques chaudes. Cependant, les tests mis en œuvre ne sont pas souvent spécifiques au sport concerné et sont difficiles à intégrer dans les programmes d'entraînement d'équipes sportives de niveau élite en raison des autres priorités d'entraînement. Sept athlètes élites de rugby à 7 non acclimatés à la chaleur (25 ± 3 ans; 95,3 ± 6,5 kg; 190 ± 3 cm) ont effectué deux tests de course spécifiques au rugby à 7 à température ambiante (20 °C, 50 % humidité relative; RUN:AMB) et à la chaleur (35 °C, 80 % humidité relative; RUN:HOT), ainsi qu'un TRC sur un ergocycle à la chaleur (CYCLE:HOT) apparié en fonction de la fréquence cardiaque (FC). Les variables physiologiques et de perception ont été collectées au cours de chaque test. La température tympanique (T_{Tymp}) moyenne, la FC, la sensation thermique, le niveau d'effort perçu, et la perte hydrique par la sueur étaient significativement plus élevés, tandis que le malaise thermique et les performances physiques étaient significativement plus faibles dans RUN:HOT par rapport à RUN:AMB (tous d > 1,40; p < 0,05). La T_{Tymp} moyenne et FC étaient significativement plus faibles dans CYCLE:HOT par rapport à RUN:HOT (tous d > 1,10; p < 0,05), sans différences claires par rapport aux niveaux de perception. En moyenne, la T_{Tymp} maximale atteinte était de 39,5 ± 0,5 °C dans RUN:HOT et 38,8 ± 0,4 °C CYCLE:HOT. Le stress thermique aigu est préjudiciable à la performance des athlètes de rugby à 7 d'Elite non acclimatés à la chaleur. La perception du stress thermique (mais pas le stress physiologique) associée à la course à haute intensité en condition chaude peut être reproduite sur un ergocycle. Le HRT basé sur le cyclisme pourrait être utilisé pour éviter une charge mécanique supplémentaire associée aux tests à la course.

1. Introduction

Heat response (or heat stress) tests (HRT) are used to assess athletes' ability to cope with the physiological and perceptual demands of exercising in the heat, along with their capacity to perform in hot conditions. HRT are commonly carried out at the beginning and end of a heat acclimation (HA) protocol to assess resulting adaptations, and also in the following days/weeks after HA to assess the persistence of adaptations [1]. Practitioners also use HRT as one-off assessments of an athlete's ability to cope with the demands of performance in the heat, including those who are returning to training in the heat following exertional heat illness [2]. In a sporting context, HRT generally contain a sustained period of fixed-load work, followed by a component of maximal exertion or time to exhaustion (such as a time-trial), which provides a performance measure in the heat [3]. Current guidelines recommend that HA protocols (and hence HRT) should be specific to the demands of an athlete's sport [4]. This specificity permits simple integration of heat stimulus into an existing training schedule, and allows athletes to experience heat stress in a situation that reflects their competitive environment which may be useful for specific post-acclimation performance [4—6]. Many HA protocols have been designed for endurance athletes, which is reflected in the design of most HRT's [1]. In contrast, HA and HRT has limited previous assessment in team sport contexts, particularly at an elite level [7,8].

Rugby sevens is an Olympic team sport characterised by repeated bouts of high-intensity running, frequent contacts, sprints, skill, and spatial awareness, played over two 7-min halves, with seven players per team [9]. Players have been reported to cover a total of ~1500 m in one game, with ~250 m being above an arbitrarily assigned high-speed running threshold of 5.0 m·s^{-1}, and maximal running velocities of 8.0 to 8.5 m·s^{-1} [9]. Every season, between December to May, the International Rugby Board (IRB) conduct the ten tournament World Rugby Sevens Series (WRSS). These international competitions are often played in hot summer environments, with temperatures as high as 45 °C (113 °F) recorded during a recent tournament in Sydney, Australia (February 2020, unpublished field observations). The combination of challenging environmental conditions and high relative exercise intensity likely combine to present a thermoregulatory challenge during elite rugby sevens competition [10], as demonstrated in a previous investigation, where high (39.9 °C) individual peak T_c values were recorded during a hot/humid tournament [11]. Furthermore, considering that the (delayed) Tokyo 2020 Summer Olympics were predicted to be the hottest on record [12], the importance of appropriate team and individual specific heat management strategies for international rugby sevens teams are clearly indicated [3,4].

Within a full-time professional rugby sevens season, it is common practice to conserve running load for specific training. In this case, off-feet conditioning is often used to compliment running exercise in order to obtain/sustain cardiovascular and metabolic adaptations, without the mechanical load-bearing stress that running exerts [13,14]. Therefore, the aims of the current research were to

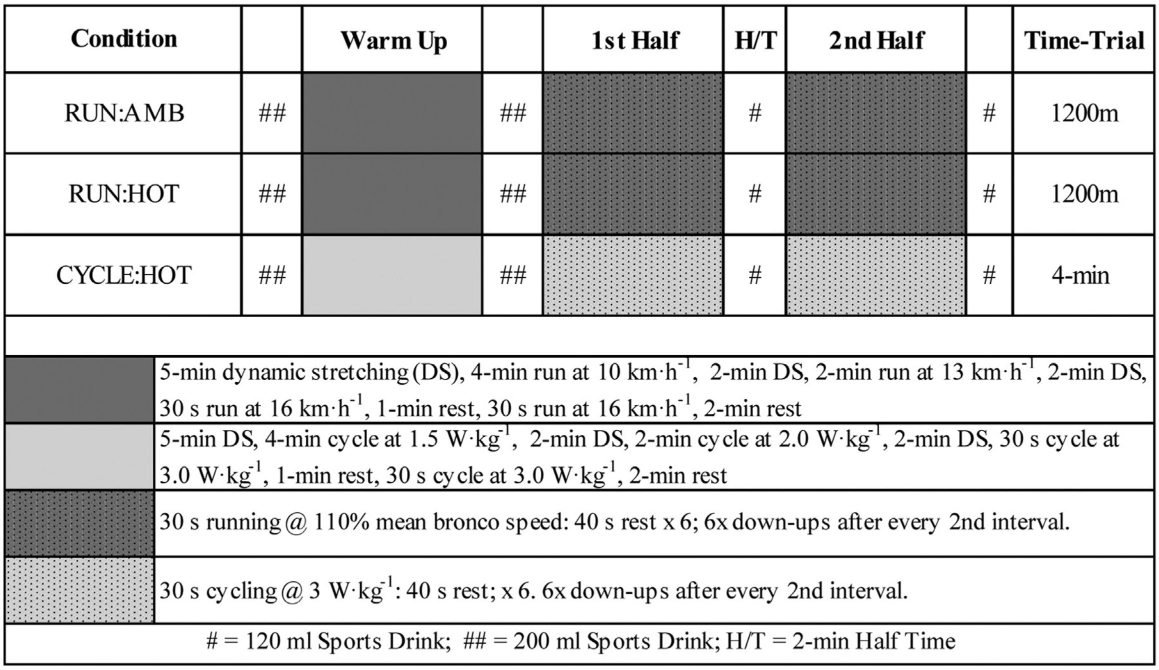

Figure 1 Schematic of the Heat Response Test (HRT) protocols.

evaluate an off-feet (cycling) HRT, that would be acceptable for practitioners to include within the normal training week of an international elite rugby sevens team. The off-feet test was designed to provide a similar physiological stimulus as a running test, while also being specific to the physiological demands of elite rugby sevens. Furthermore, the research aimed to evaluate any deleterious effects of acute heat stress on physiological, perceptual and performance responses between an ambient environment (20 °C, 50% rH) and the thermally challenging conditions predicted at the Tokyo 2020 Olympics (35 °C, 80% rH).

2. Methods

2.1. Subjects

Data was collected from seven non-heat acclimated elite male rugby sevens athletes (age: 25 ± 3 years; body mass 95.3 ± 6.5 kg; height 190 ± 3 cm; all mean ± SD) of a single 2018—2019 WRSS international team after signing written informed consent. The procedures of the study were approved by the Human Research Ethics Committee of the University of Waikato (HREC2018#64). Athletes were asked to consume the same food and abstain from alcohol and caffeine in the 12-h before each testing session. All trials took place in local springtime conditions (mean daytime high ~18 °C) throughout the teams' pre-season to avoid any natural heat acclimatisation. Participants refrained from strenuous exercise outside of the laboratory for 48-h before each testing session.

2.2. Experimental Design

Participants undertook three tests across three consecutive weeks, including a control condition (RUN:AMB) and two heat response tests (HRT; RUN:HOT, CYCLE:HOT). The two RUN conditions were completed first in a randomised cross-over design, while the CYCLE:HOT condition was completed on Week Three for all participants. All HRTs were performed in an environmental chamber set at 20 °C, 50% rH for the RUN:AMB condition and 35 °C, 80% rH for the RUN:HOT and CYCLE:HOT conditions. Participants performed all testing sessions at the same time of day (Monday a.m.) across three weeks to account for circadian rhythms [15] and weekly training schedules. During all conditions, participants consumed a standardised amount of 6% carbohydrate sports drink (Gatorade, The Gatorade Company, Inc. Chicago, IL., USA) at room temperature (200 mL pre warm-up, 200 mL post warm-up, 120 mL at half-time, 120 mL pre time-trial; 640 mL total).

2.2.1. RUN Heat Response Tests

Seven days before the first running test all participants completed a familiar 1.2 km shuttle run test (Bronco) [16] as part of their normal pre-season assessment. Individualised interval speed during the RUN HRT was equivalent to 110% of each individual's average Bronco speed, as determined from the 1.2 km shuttle run test.

Participants entered the environmental chamber and completed a 19-min progressive-intensity, standardised warm-up (see Fig. 1) followed by a repeated interval protocol and a 1200 m time trial (TT). The repeated interval protocol consisted of 30-s running at 110% of each individual's average Bronco speed (18.3 ± 0.8 km·h^{-1}), followed by 40-s rest, repeated 12 times with a 2-min half-time break after interval 6. Immediately following every 2nd interval, participants also performed five down-ups (to simulate rucking type movements in rugby sevens). The design and content of the repeated interval protocol was chosen as it replicates game average high-intensity running volume,

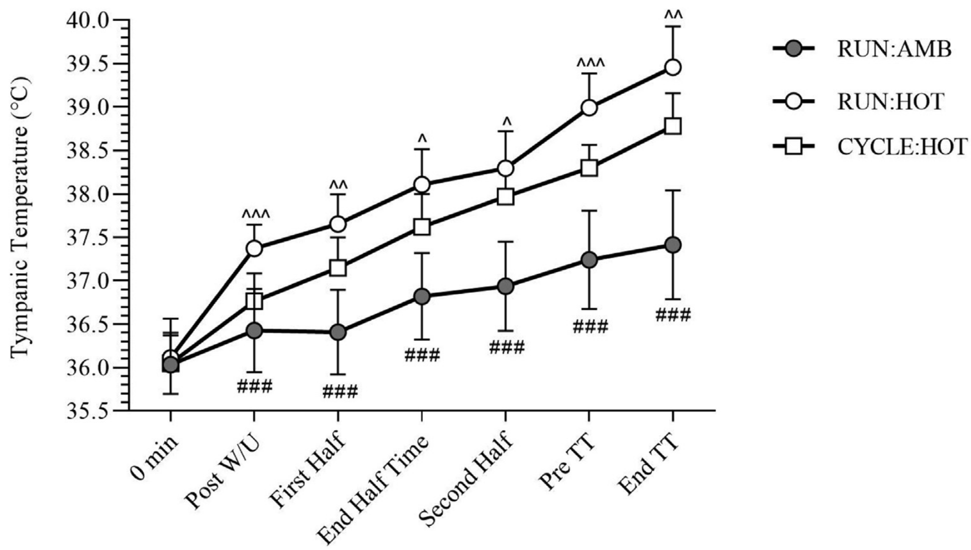

Figure 2 Mean (±90% CL) Tympanic Temperature (°C) at each measured timepoint for the three interventions. Characters displayed above/below symbols represent differences between the two comparisons as follows; # = RUN:AMB different to RUN:HOT; ˆ = RUN:HOT different to CYCLE:HOT. The presence of a symbol indicates $p < 0.01$. The likelihood of the observed effect exceeding the smallest worthwhile difference (0.3 °C) are represented by the number of symbols; 1 = *likely*, 2 = *very likely* and 3 = *most likely*.

work: rest ratios (30 s: 40 s), and dynamic rucking type movements in rugby sevens (~15 per match) [9]. The 1200 m TT was included as it is the same distance as many teams usual running performance test (Bronco), providing a simple and familiar metric for athletes and practitioners. All running was undertaken on a calibrated motorised treadmill (Life Fitness 95 T Elevation, Life Fitness, Inc. Rosemont, IL. USA.) set at a 1% incline, which most accurately reflects the energetic cost of outdoor running [17]. During the 1200 m TT, the display monitor of the treadmill was covered, and the participants were instructed to control the speed of the treadmill themselves, with distance being the only external feedback given verbally by a researcher at 200 m intervals.

2.2.2. CYCLE:HOT Heat Response Test

The CYCLE:HOT HRT was performed on a calibrated cycle ergometer (WattBike Ltd, Nottingham, UK) and consisted of the same time structure as the run tests, with exercise intensity being standardised using relative power output [watts per kg of body mass; ($W{\cdot}kg^{-1}$); see Fig. 1]. During the 30-s intervals, participants were asked to maintain a power output of 3.0 $W{\cdot}kg^{-1}$ followed by 40-s rest, repeated 12 times with a 2-min half-time break after interval 6. Immediately following every 2nd interval, participants also performed six down-ups. A power output of 3.0 $W{\cdot}kg^{-1}$ was chosen as this reflected individual mean HR during the 1.2 km shuttle run test (as described above) in pilot testing. The performance test during the CYCLE:HOT was a 4-min TT whereby the monitor of the cycle ergometer was covered, and verbal cues given by a researcher at 1000, 2000, 2500, and 2800 m. A 4-min TT was chosen as this distance takes a similar time to the running 1.2 km shuttle run test, participants were familiar with this cycle test as it is commonly used as an off-feet conditioning session during their normal training, and it has been shown to have high level of test-retest reliability (CV < 3%) [18].

2.3. Physiological Measurements

Tympanic temperature (T_{Tymp}; Braun ThermoScan® 7 IRT6520, Braun GmbH, Kronberg, Germany) and Heart rate (HR; Polar H10, Polar Electro Oy, Kempele, Finland) were sampled at 0 min, post warm-up, after intervals 3 and 6; at the end of half time; after intervals 9 and 12; Pre TT and End TT. The mean of values collected after intervals 3 and 6 was taken to calculate the first half measurement, likewise for the second half with intervals 9 and 12 (as shown in Fig. 2). Each T_{Tymp} measurement was sampled in duplicate, the mean of which was recorded for analysis. T_{Tymp} was chosen as our method of assessing body temperature as it has been previously demonstrated acceptable agreement with assessment of core temperature via telemetry pill when exercising in the heat [19] Each researcher was trained to take to measure T_{Tymp} the same way, as previously described [19].

Before the start of each test the skin of the right shoulder blade was cleaned with distilled water and dried, before adhesive gauze sweat patches (Tegaderm + Pad, 3 M, Loughborough, UK) were applied. At the completion of each test, sweat patches were immediately placed into sealed containers and frozen until analysis. Sweat sodium concentration was determined using absorbance photometry (Cobas C111 analyser, Roche, AG Basel Switzerland). To estimate sweat loss, towel-dried, nude body mass (NBM) was recorded to 0.1 kg using digital scales (Seca 877, Seca, Hamburg, Germany) before and immediately after each session, this value was adjusted for ingested liquid during the test (640 ml).

2.4. Perceptual Measurements

Rating of perceived exertion (RPE; 6—20 scale) [20], thermal sensation (TS; 1—13 point scale) [21], thermal discomfort (TDC; 1—10 point scale) [21] and thirst sensation (Thirst;

Table 1 Grouped mean (± SD) and mean differences (± 90% confidence limits (Cohens d) for all variables for RUN:AMB, RUN:HOT and CYCLE:HOT Heat Response Tests.

	RUN:AMB	RUN:HOT	CYCLE:HOT	RUN:HOT vs. RUN:AMB	RUN:HOT vs. CYCLE:HOT
T_{Tymp} (°C)	36.9 ± 0.3	38.3 ± 0.3	37.8 ± 0.2	1.4 ± 0.4 (3.09) *very large****	0.5 ± 0.3 (1.44) *large****
HR (bpm)	150 ± 5	164 ± 7	152 ± 6	14 ± 8 (1.49) *large**	12 ± 9 (1.11) *large**
TS (AU)	8.4 ± 0.8	11.3 ± 0.6	11.0 ± 0.5	2.9 ± 1.0 (2.35) *very large****	0.2 ± 0.8 (0.26)
TDC (AU)	4.2 ± 1.2	7.9 ± 0.7	6.9 ± 0.7	3.7 ± 1.4 (1.76) *large****	1.0 ± 1.0 (0.94)
RPE (AU)	13.9 ± 1.0	16.5 ± 0.7	16.3 ± 0.6	2.6 ± 1.3 (1.79) *large***	0.2 ± 1.0 (0.19)
Thirst (AU)	4.4 ± 1.0	5.3 ± 0.6	4.1 ± 0.9	0.9 ± 1.2 (0.71)	1.2 ± 1.1 (0.85)
Sweat loss (kg)	0.7 ± 0.2	1.1 ± 0.1	1.1 ± 0.2	0.4 ± 0.2 (1.62) *large**	0.0 ± 0.2 (0.09)
Sweat $[Na^+]$ (mmol/l)	71.1 ± 7.8	80.2 ± 9.3	71.0 ± 5.2	9.1 ± 11.2 (0.72)	9.2 ± 10.1 (0.81)
Time Trial	266 ± 16 s	335 ± 50 s	282 ± 13 w	66 ± 42 (1.76) *large***	—

Cohens d are qualitatively described in *italics*. AU: arbitrary units.
* $p < 0.05$
** $p < 0.01$
*** $Pp < 0.001$

1—9 point scale) [22] were collected at the same time points described above for physiological measurements.

2.5. Statistical Analysis

Raw data in tables and text are presented as mean ± SD with the mean differences and uncertainty of estimates shown as mean difference (MD) ± 90% confidence limits (CL). For all variables, the mean of all data points was calculated and used in the corresponding analysis, presented in Table 1. Each comparison (RUN:HOT vs. RUN:AMB; RUN:HOT vs. CYCLE:HOT) was analysed separately to assess the size of effect (Cohens *d* effect sizes; ES), statistical significance (resulting from paired sample *t*-tests), and practical meaningfulness using specifically designed customisable spreadsheets [23]. If the 90% CL overlapped positive and negative trivial (±0.20) ES values, the effect was deemed unclear. Cohens *d* ES and 90% CL were characterised using standard thresholds of < 0.20 trivial, 0.21—0.60 small, 0.61—1.20 moderate, 1.21—2.0 large, and > 2.0 very large [24]. T_{Tymp} was further analysed using two-way repeated measures ANOVA to determine if there were differences between conditions and across time using the Šídák—Bonferroni correction for pairwise multiple comparisons. Normality and homogeneity of variance of residuals were checked using quantile-quantile (Q-Q) and scatter plots, which were deemed plausible in each instance. The smallest worthwhile change (SWC) for each variable was presented as it provides information regarding practical meaningfulness, which is most relevant to sport performance [25]. The smallest worthwhile change (SWC) for thermoregulatory and perceptual variables were determined from a recent meta-analysis on responses to HA [1] and are as follows; resting T_{Tymp} (0.2 °C), exercise T_{Tymp} (0.3 °C), submaximal HR (9 bpm), peak HR (12 bpm), thermal sensation (0.9 AU) thermal discomfort (0.9 AU), thirst (0.9 AU), and RPE (1.0 AU). The SWC we used for resting and exercise T_{Tymp} were based upon the SWC that Tyler et at., (2016) reported for core temperature (T_{core}), as T_{Tymp} is a valid measure of T_{core} when exercising in the heat [19]. The SWC for the time-trial in each condition was estimated by taking one third of the population coefficient of variation CV % for each measurement, based from previous reliability data collected in our lab (1200 m TT SWC = 2.2%; 4-min TT SWC = 2.7%). Magnitudes of the smallest worthwhile change (fSWC) as follows; small (1.1—2.9 x SWC), moderate (3.0—5.9 × SWC), large (6.0—9.9 × SWC) and very large (> 10 × SWC). For fSWC data, quantitative chances of higher or lower differences were evaluated qualitatively as follows; 75% to 95%, likely; 95% to 99%, very likely; and >99%, most likely.

3. Results

During RUN:HOT, mean T_{Tymp}, HR, TS, RPE, sweat loss, and time to complete the 1200 m TT were significantly higher, and mean TDC was significantly higher (less comfortable) than RUN:AMB (Table 1). During CYCLE:HOT, mean T_{Tymp} and HR were significantly lower than RUN:HOT (Table 1). Mean differences, effect sizes and statistical significance are presented in Table 1 and the magnitude of these differences are presented in Fig. 3A—B.

4. Discussion

The current investigation was the first to our knowledge to investigate and compare the effects of acute heat stress during both on and off-feet exercise in an elite rugby sevens population. Acute heat stress resulted in large increases in physiological and perceptual thermal strain when compared to the same exercise stimulus performed in ambient conditions. Furthermore, it was shown that these increases in thermal strain were associated with a large performance decrement during a 1200 m running TT (Table 1; Fig. 3A). When comparing running to cycling HRT's, moderate — large physiological differences were evident, whereas no clear effects on any variables associated with perceptual thermal heat stress were observed (Table 1; Fig. 3B).

Previous research involving other international sevens teams indicate that T_{core} values during competition in the heat can regularly exceed 39.0 °C [11], values above which have been shown to impact high-intensity intermittent [26]

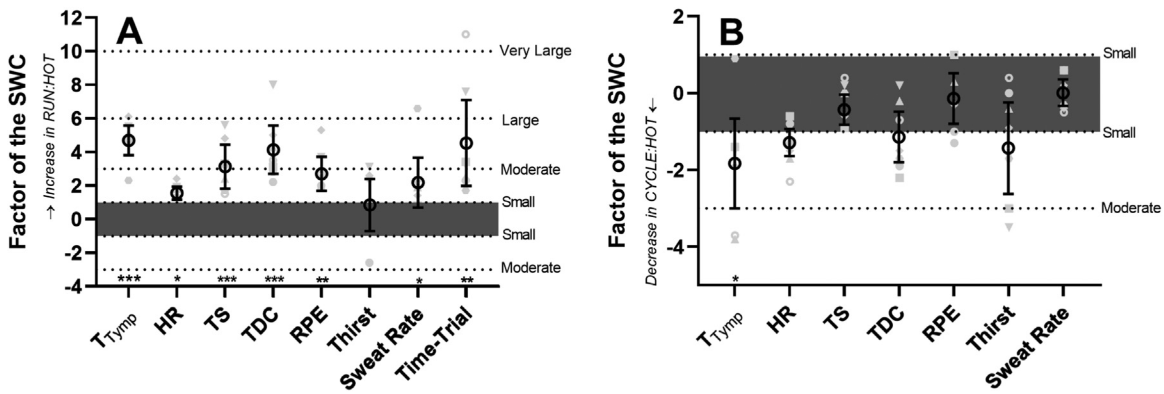

Figure 3 A, B. Changes (mean ± CL) in thermoregulatory markers including Tympanic temperature (T_{Tymp}), Heart Rate (HR), Thermal Sensation (TS), Thermal Discomfort (TDC), Rate of Perceived Exertion (RPE), Thirst, Sweat Rate and Performance during different heat response testing protocols; Panel A = RUN:AMB - RUN:HOT; Panel B = RUN:HOT - CYCLE:HOT. Light grey symbols represent individual data points with each shape representing one individual. Changes are presented as the factor of the smallest worthwhile change (SWC; grey shaded area) and the magnitude of the effect is quantified as small (1x SWC), moderate (3 × SWC), large (6 × SWC) and very large (10 × SWC). Quantitative chances are represented as *likely, **very likely, ***most likelychances of an increase/decrease.

and prolonged [27] exercise performance. Given that mean T_{Tymp} was > 39.0 °C toward the end of the RUN:HOT condition (Fig. 2), and increased cardiovascular demand was evident during exercise in the heat (Table 1; Fig. 3A), it is most likely that that the performance decrement shown in the current study can be explained by physiological factors known to impact prolonged exercise. Furthermore, the increases in T_{Tymp} and cardiovascular demand are likely to have been exacerbated by mild dehydration (NBM loss was 39% greater in RUN:HOT compared to RUN:AMB) [28] due to enhanced thermoregulatory demand for skin blood flow [10]. These acute physiological responses act to drive the perceptual response [29], as seen in the current study where TS, TDC and RPE exhibited large increases during RUN:HOT compared to RUN:AMB.

The current investigation indicates that a cycling-based HRT can be successful in reproducing the acute perceptual stress associated with a running-based HRT. Physiological differences were evident however, with higher T_{Tymp} and HR observed when running compared to cycling in the heat (Table 1; Fig. 2 and Fig. 3B). These findings concur with previous research that indicates higher VO_2 and HR in treadmill vs. cycle ergometer exercise at submaximal and maximal intensities [30]. Differences in activated muscle mass and posture contribute to differences in the cardiovascular and metabolic demands of running and cycling [31]. We postulate that the addition of full-body weighted exercise (down-ups) in the current study acted to blunt this difference seen in direct comparison studies. It has been shown that RPE can be higher within non-cycling experts during cycling vs. physiologically matched treadmill exercise [30,32]. However, during the current investigation there was no difference in RPE between running and cycling based HRT, despite increases in physiological stress during RUN:HOT, possibly indicating that the increase in physiological stress associated with running was offset by cycling being a non-specific secondary exercise mode for the athletes in the current investigation.

HRT are most often used pre and post an HA block to assess the resulting adaptations, with a rectal temperature of ∼38.5 °C claimed to be the criterion to elicit heat adaptations during controlled hyperthermia HA protocols [4]. In the current study the 45 min cycling-based HRT elicited an end-exercise T_{Tymp} of 38.8 ± 0.4 °C (Fig. 2). In turn, previous research has suggested that partial HA is possible after as little as four 30-45 min high-intensity cycle sessions in hot/humid conditions on consecutive days [33]. Together, these findings indicate that practitioners may be able to utilise short-duration high-intensity off-feet protocols, similar to the cycling-based HRT, to provide an adequate thermal stimulus to elicit heat adaptations [34,35]. This is useful for elite team sport practitioners, demonstrating the potential for traditional long-duration running-based heat training sessions to be replaced with sports-specific low impact alternatives. We also note that the thermal stimulus could be lengthened by the addition of pre- or post-session passive heat stress, which is most likely to reflect circumstances that are acceptable and practical to include within an elite team sports training schedule [5,36].

4.1. Practical applications

To our knowledge, the present investigation was the first to demonstrate the detrimental impact that acute heat stress can have on performance in non-heat acclimated international rugby sevens athletes. With many major rugby sevens events worldwide being held in thermally challenging environments, practitioners need to consider how they can integrate HA into their pre-competition schedule, without foregoing other training priorities. While the use of a cycling-based HRT can replicate the perceptual stress of a similar running test in the heat, the physiological strain whilst running was greater. Practitioners working with running team sport athletes should be aware of this when designing and assessing HA protocols. When using cycling as an exercise heat stress, methods to exacerbate the thermal impulse could be considered, such as increasing exercise time/intensity or including pre/post passive heat.

5. Conclusion

Acute heat stress causes large increases in physiological and perceptual strain, resulting in detrimental performance outcomes in non-heat acclimated elite rugby sevens athletes. High-intensity running in the heat induces high physiological strain and additional mechanical load that may not be suitable for elite team-sport athletes, meanwhile, high-intensity cycling in the heat can replicate the perceptual, but not the physiological strain associated with high-intensity running in the heat.

Disclosure of interest

The authors declare that they have no competing interest.

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