Influence of intervals of radiant heat on performance and pacing dynamics during rowing exercise.

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Abstract

The purpose of this study was to investigate whether intervals of radiant heat during thermoneutral exercise altered either the performance outcome or the dynamics of pacing within the exercise bout.

Eleven male participants ($\dot{V}O_{2peak}$; 56 ± 12 ml·kg^{-1}·min^{-1}) performed three 5000m exercise trials on a rowing ergometer in three different conditions, in a random order. The participants were either: non-warmed (NW), warmed (W), or periodically warmed in intervals throughout each trial (IW). Warming was achieved using radiant heat lamps to raise the localised environmental temperature from 18 ˚C to 35 ˚C. Intervals of warming were applied over fixed periods of the 5000m bouts between 1000-2000m (W1) and 3000-4000m (W2).

The results of the experiment demonstrated that performance time and average power output of the 5000m matched intensity trials were not significantly different between conditions ($p=0.10$; $p=0.189$). However, the application of warming significantly reduced intra-trial power output during the first (W1) interval in the IW condition ($p=0.03$) but not during the second (W2) warming interval ($p=0.10$). T_{sk} increased by 0.51˚C ($p=0.05$) in response to the application of warming during W1 in the IW condition and by 0.15 ˚C in W2 ($p=0.28$). No significant between-condition differences were observed in T_c throughout the trials.

These findings suggest that an abrupt change to environmental conditions brought about through intervals of radiant warming can affect the transient pacing dynamics of an exercise bout, but not necessarily impact overall performance time. Performance time appears unaffected by intervals of radiant heat during an exercise bout, although further work is required in more challenging dynamic environmental conditions.

Introduction

Periodic bursts of radiant heat from the Sun during otherwise cool environmental conditions are a common feature of racing in outdoor sports events and yet its impact on pacing and performance has rarely been examined [1, 2].

Previous studies indicate that intra-trial fluctuations of power output enable the performer to vary effort as part of a behavioural response to optimise performance and defend challenges to homeostasis [3-5]. The environmental conditions under which the exercise bout is performed have the potential to change at regular intervals during outdoor performance. Dynamic intra-trial fluctuations alter pace during exercise performance and are therefore likely to be resultant of many internal and external factors, probably mediated by complex metabolic control [5].

A progressive increase to core temperature is a well-known feature of endurance exercise [6] and this can be exacerbated in hot conditions, leading to premature sensations of fatigue and impaired performance when compared with exercise in an equivalent thermoneutral environment [2, 7]. Self-paced exercise performed at a fixed rating of perceived exertion (RPE) [8] therefore provides a unique opportunity to examine the influence of radiant heat on voluntary exercise behaviour during an endurance performance. Previous studies have observed reductions in power output at the onset of self-paced exercise in the heat in both cycling and running events [1, 9]. In addition, these reductions in power output were observed prior to elevation of body temperature [10], suggesting the presence of an influential anticipatory central regulatory process.

The use of a pacing strategy is a well-known factor in racing determined by pre-race considerations of task severity and intra-trial factors [5, 11]. Tucker et al., demonstrated that participants in a bout of self-paced cycling reduced power output after only 30% of trial duration in warm conditions [2]. This early behavioural reduction in power output occurred despite similarity of rectal temperatures (T_{re}). The reduction in power output prior to a significant difference in T_{re} was proposed to be part of an anticipatory response to ensure that relative thermal homeostasis was retained in altered environmental conditions.

To date, no studies have investigated the influence of applications of intervals of radiant heat on pacing or performance during an exercise bout. Therefore, the purpose of this study was to compare pacing and performance in response to the imposition of 1) intra-trial intervals of radiant warming with 2) thermoneutral and 3) constant radiantly warmed conditions. It was hypothesised that the transient intra-trial introductions of radiant warming would evoke an alteration (down-regulation of power output) to the pacing of an exercise bout during the period of warming compared to either stable thermoneutral or warmed conditions.

Methods

Eleven healthy, well-trained male participants were recruited and agreed to take part in this study (Table 1). All were informed of the procedures in advance and informed consent was provided prior to any data collection. The study was approved by the Central Regional Ethics Committee of New Zealand and by the

Faculty Research Committee at Leeds Metropolitan University, UK. All participants were recreational gymnasium users and each received technical advice from a qualified rowing coach on rowing ergometer use during a two-week familiarisation period. On each laboratory visit participants completed a four stage incremental exercise protocol the initial stage required participants to work for 4min at RPE 11 (Light), each subsequent stage increased in intensity and decreased in time (3min: RPE 13 (Moderate), 2min: RPE 15 (Hard), 1min: RPE 19 (Very Very Hard)). This protocol was used to confirm the replication of effort in accordance with RPE anchors and as a standardised priming exercise in each of the trials.

Following a separate visit for an assessment of peak aerobic power ($\dot{V}O_{2peak}$) using a protocol previously described by Smith and used in assessments by the National Sport Organisation; Rowing New Zealand [12] each participant completed three, 5000m rowing trials in three different experimental conditions, in an individually randomised order in a laboratory setting on a Concept 2 rowing ergometer (Model D: Concept 2, Tauranga, NZ). In condition one, participants completed 5000m at a constant rating of perceived exertion (RPE: 15-Hard) whilst being radiantly warmed at two intervals (condition: IW) between 1000-2000m (W1) and from 3000-4000m (W2). In condition two, participants performed 5000m at a constant rating of perceived exertion (RPE: 15-Hard) whilst not being warmed (condition: NW) at any point in the trial. In the third condition, participants performed 5000m at a constant rating of perceived exertion (RPE: 15-Hard) whilst being constantly radiantly warmed (condition: W) throughout the 5000m trial. The intervals of warming in the intermittent condition were applied between 1000-2000m (W1) and from 3000-4000m (W2) without prior warning within the bout. The instantaneous nature of the warming mechanism immediately altered the environmental conditions for participants.

Ambient laboratory temperature was standardised at 18˚C across all tests while relative humidity remained consistent (35-45%). Radiant warming in the W1, W2 intervals and in the Warmed condition was induced using a lighting rig (adapted from Twin Flood Tripod, Arlec, Victoria, AU) with either warming bulbs (Siccatherm R125 250 Watt Red Bulbs) (OSRAM, Auckland, New Zealand), or placebo bulbs (Philips Partytone PAR38 80 Watt Red Bulbs) (Philips Lighting, Wellington, New Zealand). Placebo, non-warming bulbs were used to match the increases in light brought about through the use of warming bulbs. Therefore the only detectable change to experimental conditions for the participants was the increase in warming brought about by the warming bulbs. Protective eyewear was worn by the participants at all times during all trials (UVEX Duoflex 9180-945, UVEX Auckland, NZ). Warming raised the temperature of the localised region surrounding the athlete to ≈ 35˚C (Kestrel 2000 Wind Meter, Nielsen-Kellerman, Boothwyn, PA, USA). The lighting rig was individually repositioned prior to each trial to produce consistent heating across the length of each participant’s stroke. Air temperature was measured at three locations within the stroke (catch, mid-drive, start of recovery of the rowing stroke) prior to any trial to eliminate cool spots created by each participants individual length of stroke.

Participants were not made aware of the true purpose of the investigation or the systematic changes in pacing that the heating bulbs were hypothesised to elicit. Individuals paced each bout without feedback from the ergometer display but in the knowledge of distance covered at each 1000m within the 5000m bouts, an RPE chart was visible to participants throughout the trial, and participants were positively verbally encouraged and regularly reminded to maintain the required intensity of effort throughout the trial.

Stroke-to-stroke power output (PO) from the Concept 2 rowing ergometer was assessed using the RowPro v2.006 software (Digital Rowing, Boston, MA, USA) in conjunction with the Concept 2 interface. In all conditions the air resistance of the ergometer flywheel was standardised by using the damper lever to apply a pre-determined drag factor (130 10^{-6} $N \cdot m \cdot s^2$) [12-13].

Oxygen uptake (Cortex MetaMax 3B, Cortex Biophysik, Leipzig, Germany) and heart rates (S610i, Polar, Kempele, Finland) were continuously recorded throughout all exercise tests. Core temperature (T_c) was measured at 30 second intervals throughout each trial via telemetry from the intestine using a silicon-coated thermometer pill (CorTemp2000, HQ, Palmetto, Florida, USA) which was swallowed by all participants 5-8 hours before exercise. A four-stage temperature calibration of the pills against a certified mercury thermometer in a water bath at temperatures ranging from 34°C to 40°C was conducted prior to pill ingestion. In accordance with earlier work, a linear regression equation was then used to adjust pill measurements [14]. Skin temperatures (T_{sk}) were measured at 30 second intervals throughout each trial at four sites (chest, upper arm, upper leg, lower leg) using stainless steel surface skin thermistors (Grant Logistics, Cambridge, UK) securely taped to the skin (Micropore, 3M, Auckland, NZ). Temperatures were recorded continuously throughout the trial using a data logger (SQ400 Squirrel Data logger, Grant Logistics, Cambridge UK). Mean skin temperature was calculated using the formula previously described by Ramanathan [15].

All measures of performance and physiological variables were taken continuously throughout the trials in order to assess dynamic responses within each exercise bout.

Dynamic variations attributable to pacing were assessed by the measurement of heart rate and power output which were recorded individually and transformed into 30s measures to reduce data noise and create comparable measurement intervals. Due to individual variations in the time to complete 5000m, the full bout duration was considered as a value of 100% and measures were then time aligned and batched into 5% bout means for each outcome measurement.

The statistical software packages SPSS (version 11.0, SPSS, Chicago, IL, USA) and GraphPad Prism (version 4, GraphPad Software Inc, La Jolla, CA, USA) were used for statistical analysis. Results were assessed for normal distribution then statistically compared using one-way repeated measures analyses of variance (ANOVA) with post-hoc Bonferroni correction statistics. Other comparisons were made using paired Student's *t*-tests. Pearson product moment correlations were used to calculate r values. Probability values of less than 0.05 were considered significant. All results are expressed in means ± SD.

Results

There were no differences in the mean power output between interval warmed (170 ± 12W), and stable thermal conditions (NW 172 ± 16W; $p=0.617$, W 174 ± 21W; $p=0.189$). Nor in the performance times for the three conditions (Table 2).

To identify dynamic intra-trial changes in variables, each physiological and performance response was interpolated into 5% batches of trial performance time. The 5000m bout was completed in a range of between: 1264 ± 57s to 1270 ± 68s, thus 5% of the trial duration equates to approximately 60s of exercise.

In each condition, participants exerted their peak power output within the first 10% of the trial ($p<0.05$) compared with all subsequent 5% measures. Similar patterns of self-paced effort were observed in the constant warmed and non-warmed trials such that W and NW trials were not significantly different when compared at any discrete 5% of trial duration ($p>0.05$). Figure 2 shows the power output in the intermittent warming experimental condition. Periods of warming and non-warming are indicated by an alternating solid and checked bar along the *x*-axis.

Analysis of dynamic variations in power output in the IW condition showed that the first warming interval caused a significant reduction (6%) in power output during W1 ($p=0.03$) compared to the power output at the start of the warming period. However a decrease in power output of only 4% was observed during W2 which failed to reach significance ($p=0.10$) (Figure 3).

Following an initial rise in heart rate no differences in heart rate were also observed from 10% trial completion onwards. Final heart rates were 162 ± 20 $b{\cdot}min^{-1}$ in the IW, 161 ± 16 $b{\cdot}min^{-1}$ in the NW and 165 ± 19 $b{\cdot}min^{-1}$ in W conditions respectively ($p>0.05$) and were not significantly different from the mean within each exercise bout.

Core temperature measures revealed no significant differences between start and end core temperatures. Rises of 1.11 ± 0.62˚C, 1.20 ± 0.5˚C, and 1.18 ± 0.08˚C were demonstrated in the IW, NW and W conditions respectively from baseline to trial completion ($p>0.05$). Final core temperatures were 38.55 ± 0.27˚C in the IW condition, 38.64 ± 0.31˚C in the NW condition, and 38.38 ± 0.30˚C in W condition

Changes in the interval warming condition reflected a distinct condition specific response. Analysis of dynamic variations revealed a significant increase in T_{sk} of 0.51˚C in the interval warmed condition between 20-40% trial completion in response to the first warming interval ($p=0.05$). This equated to a rise in T_{sk} of 1.65% over the W1 interval. The second warming interval from 60-80% trial completion caused a rise of 0.15˚C or 0.47% over the interval but this value failed to reach significance ($p=0.28$). These changes in T_{sk} are plotted in conjunction with changes in power output in Figure 3.

Pearson product moment correlations revealed significant relationships between core temperature (T_c) and performance time ($r=0.828$), T_c and power output ($r=0.826$), and T_c and heart rate ($r=0.815$) in the IW condition. There were no correlations between these variables in the warmed and non-warmed conditions.

Finally qualitative feedback from participants noted that the use of warming lights was not perceived as off-putting in any condition, and despite the ability to change the local temperature from ≈18˚C to ≈35˚C in a short space of time, 25% of the participants commented that they did not immediately notice when the warming commenced in the interval trial.

Discussion

The main observation from this study was that the introduction of intervals of radiant heat (35˚C) to a thermoneutral environment (18˚C) (IW condition) resulted a significant reduction to power output (p=0.03) over the first warming period (W1) but that this dynamic down-regulation of power output, which altered the intra-trial pace of the performance, did not compromise the overall performance time compared to either a thermoneutral or a constant heat condition.

Whilst significant reductions in pace were seen in the first warming period the second period of warming (W2) did not initiate a significant reduction in power output, suggesting that dynamic, intra-trial fluctuations of environmental conditions are more influential in the early stages of exercise when the potential for outcome success is less well established. This observation is consistent with the recent work of de Koning et al., who have proposed that performers regulate pace based on the perceived "hazard" of catastrophic failure derived dynamically from multiple physiological mechanisms [11]. This study, which is the first to demonstrate the influence of intervals of radiant heat on dynamic power output and performance during a self-paced bout of exercise, furthers the work of de Koning by demonstrating that the overall performance of an exercise bout seems robust despite intervals of increased "hazard" brought about through radiant warming.

The observation of intra-trial fluctuations of power output without alteration to an overall outcome measure has previously been described by Edwards and Noakes [3]. The authors proposed the presence of a multi-level pacing strategy, such that an overall race outcome (macro pacing) is informed and defended by meso (periodic) and micro (immediate) intra-trial fluctuations of effort.

In this study the significant reduction in power output (6%) (p=0.03) during the first warming period (W1) of IW, in the absence of overall differences in performance, demonstrates that participants were able to dynamically alter their pacing strategy without impacting on overall performance. It seems plausible that at different stages of an exercise bout radiant warming could be more or less influential dependent upon knowledge of the effort subsequently required to complete the bout. In the early stages of an exercise bout, it is likely that sensations of premature warming are perceived as detrimental to performance and thus performance reduced. Later in the bout, other factors (such as changes to blood pH) may become more influential within complex metabolic control. However further research is required to confirm this hypothesis.

Although the multiple levels of pacing seen in this study are in accordance with the Edwards and Noakes model of multi-level pacing strategies [3], it might be expected that this early reduction in effort should have consequently been balanced by an increase in power output later in the bout in order to match the expected effort required for the overall performance. This was not identified by a measurable subsequent upturn in power output in the IW condition when radiant warming was removed. However, as the overall performance outcome was the same between conditions, it may be suggested that gradual minor gains in power output were experienced after the first warming period but were probably too small to detect via intra-trial statistical testing. Indeed it is likely that any increases in power output following an unexpected environmental challenge are applied gradually throughout the remainder of the bout rather than manifesting as a singular immediate increase in effort. Further research is required to confirm this observation.

The inconsistency between these findings and the theoretical increase in power later in the bout predicted by the Edwards and Noakes model [3] may also be attributed to the use of the RPE clamp in the trial which limited participants by asking them to maintain an effort equivalent to RPE 15 consistently throughout the bout. Whilst the combination of the clamp and thermal disturbance would result in a reduction in their effort in the first period of warming, with a large proportion of the trial still unknown, the clamp would not allow for an increase in effort in the latter stages of the bout when participants are more confident of the effort yet to come, and thus more likely to consider increasing intensity accordingly. The repetition of this study with the removal of the clamp and incorporation of a time-trial scenario may elicit further understanding of the concept of multi-level pacing plans.

The observation of aspects of a multi-level pacing strategy in self-paced rowing in this study is in addition to the description of such strategies in football and world record athletics [3, 16] and suggests that the ability to alter pace may no longer be considered a singular shift within a bout of exercise. The impact of challenges during exercise may therefore be influenced by the point at which they are applied during a trial. Noakes et al., have previously identified that in order to complete a world record mile the greater application of effort is most often exerted in laps 1 and 4 rather than laps 2 and 3 [16]. In the current study, the disturbance to power output was brought about by changes in the thermal environment, this disturbance, seen in the first warming interval was not seen the second warming interval. The timing of this application within a pacing strategy may, in part, also explain the findings of Schlader et al., who observed a greater impact of consistent changes in temperature on exercise intensity upon the commencement of exercise than during the remainder of a 60min cycling exercise trial [17].

Evidence of the altered impact of thermal challenges, dependent upon their point of application in a bout, may be demonstrated by the disturbance to power output caused by interval warming in the first warming interval, which was however not significantly different during the second interval ($p=0.10$) (W2). Indeed the effect of the second bout of warming on skin temperature was 29% less than that of the first bout of warming. The difference in the down-regulation of power in response to warming intervals should be considered in the context of the mean skin temperature at the time of application within the bout. It is possible that the first warming interval caused a greater fluctuation in skin temperature, and consequently power, than the second warming interval as a consequence of the altered blood flow to the periphery which occurs during exercise [6]. Future research could further elucidate this hypothesis by using warming strategies indexed to skin temperature to create similar relative increases in the thermal environment.

Previous studies involving self-paced exercise have identified a reduction in effort prior to changes in core temperature [2, 4]. The data from this study does not show a significant difference in intra-trial core temperatures across the three conditions, which may also be a consequence of the relatively minor perturbation in temperature stimulus employed in this study. It is recommended that future work consider greater changes in temperature. It should be noted that in each of the previous studies which have demonstrated an anticipatory reduction in power output, participants were asked to complete a set amount of work in the quickest time possible. Such protocols could be considered maximal self-paced trials, rather than the sub-maximal self-paced exercise trial employed in the present study, in this context it becomes more apparent why differences in physiological variables in this study might have a lesser magnitude. This presents an interesting dichotomy in which an anticipatory reduction is seen in maximal self-paced exercise but not in sub-maximal self-paced exercise, which may be of interest to future research.

Average core temperature (T_c) and mean skin temperatures T_{sk} have been previously suggested to have an inverse relationship in order to maintain thermoneutrality [19]. In the presence of the changing thermal environment in the interval warmed condition the changing influence of these physiological parameters cannot be overlooked. The work of Frank et al., has previously shown that skin temperature is as likely as core temperature to influence thermoregulatory behaviour in humans at rest [20]. Furthermore, Flouris and Cheung have shown that during 10min of exercise participants selectively adopt a strategy in order to maintain thermoneutrality [21]. It is certainly plausible that the reduction in power output in the first warming period of the current study was in response to an unanticipated increase in skin temperature thus bringing about a behavioural change. The practical application of this information is unclear, however it could be suggested that, based on this evidence, a strategy of early intervention may have a better chance of disrupting an opponent's strategy than one introduced later in an exercise bout.

Irrespective of condition, an end-spurt in power output at 80-85% can be observed in each of the three conditions. The end-spurt, initially identified by Catalano [22], seems to be an integral part of self-paced exercise bouts, and in the current study, occurred at a similar time and to a similar amplitude in spite of different thermal conditions. The mechanisms behind such a consistent behaviour clearly require a more detailed exploration, but it is suggested that an end-spurt of effort may be a core component of any self-regulated multi-level pacing strategy a view supported by the work of Thomas et al., who have recently demonstrated the reproducibility of pacing strategy during 20km time-trial with specific interest to strategies employed at the start and end of the time-trial [23].

To conclude this study has demonstrated that over a 5000m time-trial participants were able to match an RPE 15 (hard) perceived effort despite the introduction of either intervals of radiant warming or constant radiant warming in an otherwise thermoneutral environment. In an interval warming environment, participants in this study significantly reduced power output in response to the initial thermal challenge ($p=0.03$). Significant correlations between physiological and performance responses were observed in the interval condition which were not apparent in the constant thermal conditions. This ability to significantly alter a pacing plan during exercise without change to the overall outcome measures is evidence of the use of multi-level pacing plans during a bout of self-paced exercise; however the influence of changes may be contingent upon the period of the exercise bout in which they are applied.

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Tables

Table 1 Anthropometric and cardiovascular characteristics of study participants.

	Participant Characteristics (n=11)				
	Height (m)	Weight (kg)	Age (years)	$\dot{V}O_{2peak}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	HR at $\dot{V}O_{2peak}$ ($b \cdot min^{-1}$)
Mean ± SD	1.79 ± 0.05	80.05 ± 13.7	30 ± 7	56 ± 12	183 ± 11

Table 2 Mean performance times and thermal responses of participants in three experimental conditions.

	Performance Time (s)	Power Output (Watts)	Core Temperature (˚C)	Skin Temperature (˚C)
IW	1270 ± 68	170 ± 12	38.6 ± 0.3 ‡	31.0 ± 0.4 ‡
NW	1268 ± 61	172 ± 17	38.7 ± 0.3	31.3 ± 0.2 (nd W p=0.09)
W	1264 ± 57	174 ± 21	38.4 ± 0.3 ‡	31.2 ± 0.2 (nd IW p=0.07)

* Sig diff W p<0.05 ; ‡ Sig diff NW p<0.01 ; nd No significant difference, IW= Interval Warmed, NW=Non-Warmed, W=Warmed.

Figures

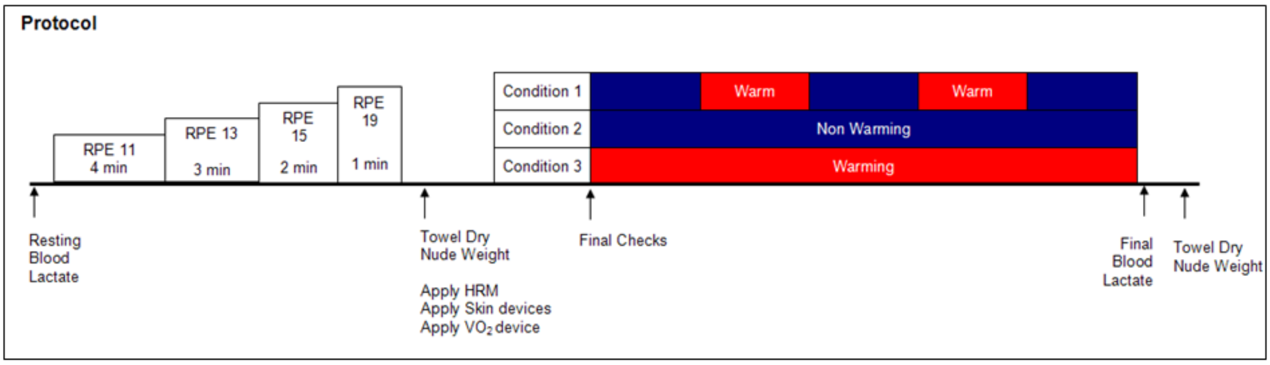
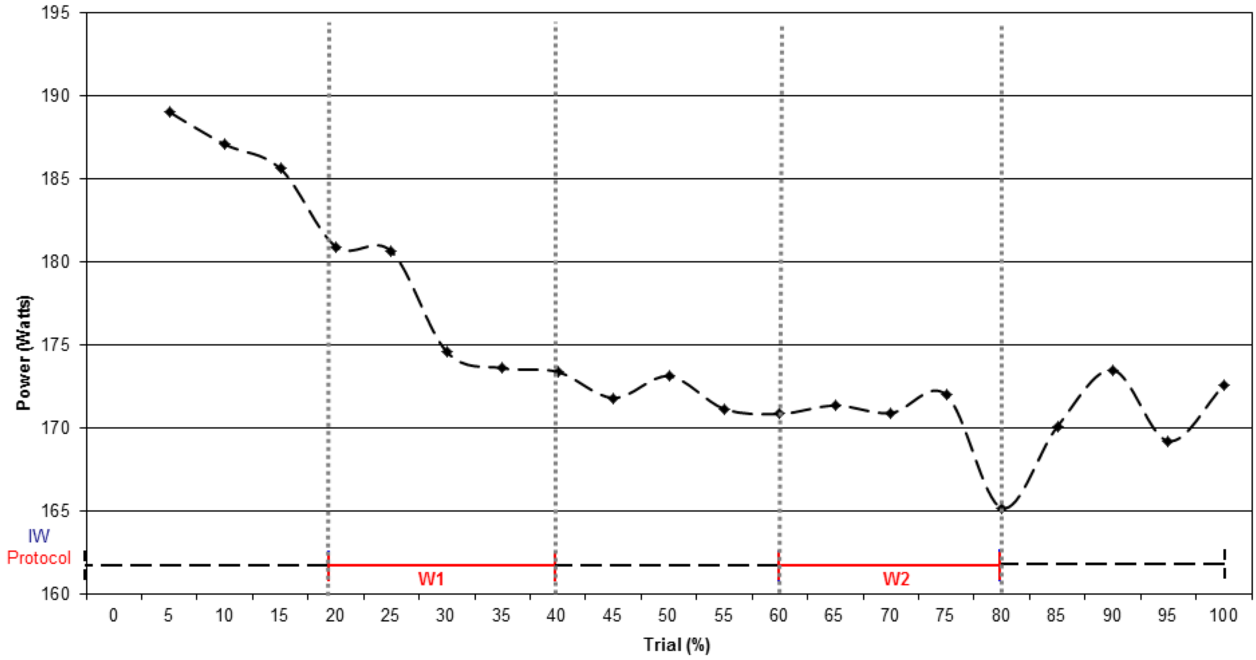


Figure 1 Diagrammatic representation of the warm-up and protocol in three experimental conditions.

Condition 1: Interval Warming; 5000m RPE 15 warmed with heating bulbs for 1000m intervals. **Condition 2:** Non-Warming; 5000m RPE 15 non-warming placebo bulbs lit throughout the trial. **Condition 3:** Warming; 5000m RPE 15 warmed with heating bulbs throughout the trial.



	Power Output (W)					
	25%	40%	Delta	65%	80%	Delta
IW	182 ± 33	171 ± 34	11W 6% (p=0.03)	173 ± 29	166 ± 26	7W 4% (p=0.10)

Figure 2 Mean power output in the intermittent experimental condition expressed as a function of percentage trial completed.

No significant differences observed in power output at any 5% interval.

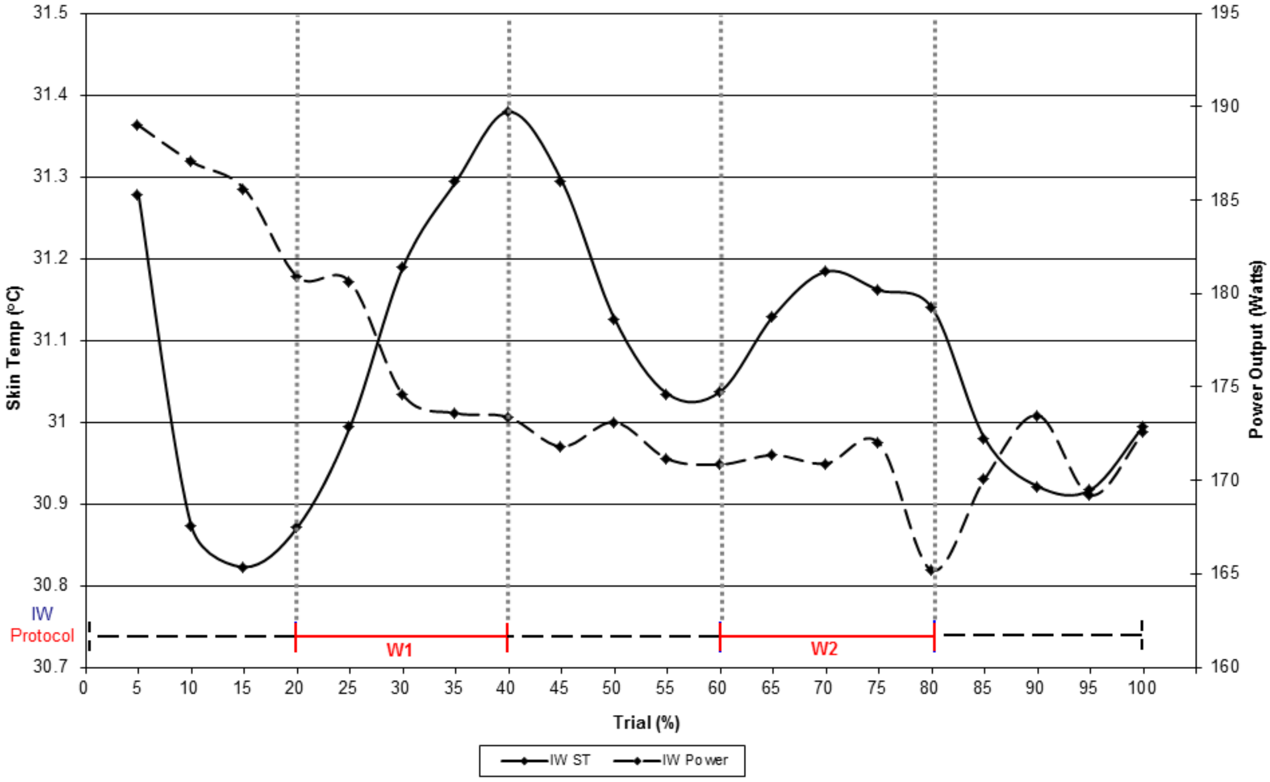


Figure 3 Mean skin temperature and power output in the interval warmed condition expressed as a function of percentage trial completed.

Significant increase in T_{sk} seen in W1 (p=0.05) but not in W2 (p=0.28)