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Hand and forearm cooling: Exploring deep-body cooling in hyperthermic individuals following exercise-induced heating at three different work rates

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Abstract: The purpose of this study was to evaluate upper-limb cooling following (treadmill) exercise performed in the heat (33°C, 70% relative humidity) at each of three speeds: light (6 km.h^{-1}), intermediate (8 km.h^{-1}) and moderate intensity (10 km.h^{-1}). In all trials, exercise ceased when rectal temperature reached 39.0°C. Participants adopted a sitting position for a 20-min recovery, and liquid-cooling sleeves with cold water (6.3°C) were immediately positioned. The chosen work rates resulted in a two-fold difference in exercise duration across those trials, which terminated without significant between-trial differences within either auditory canal or rectal temperatures. Auditory canal temperature elevation rates became progressively faster as the work rate increased: 0.03°C.min^{-1} (light), 0.05°C.min^{-1} (intermediate) and 0.07°C.min^{-1} (moderate) (p<0.05). However, heat extraction during recovery did not differ among those treatments: -11.2 W (SE 0.5; light), -11.8 W (0.6; intermediate) and -12.3 W (0.5; moderate; p>0.05). That outcome was reflected in auditory canal cooling rates (0.03°C.min^{-1} [light], 0.04°C.min^{-1} [intermediate] and 0.05°C.min^{-1} [moderate]). Nevertheless, rectal temperatures continued to rise throughout recovery. It is concluded that heat extraction from moderately hyperthermic individuals, using upper-limb cooling sleeves, appears to be equally rapid, regardless of heating speed, providing the same level of hyperthermia was attained prior to initiating treatment.

Key words: Heat extraction, Hyperthermia, Passive cooling, Post-exercise cooling

Introduction

Human hands and feet are ideally suited to the dissipation of excess body heat[1)], and serve functionally similar heat-loss roles to the ears of elephants[2)] and the bills of toucans[3)]. The utility of that mechanism for heat exchange, as a method for whole-body cooling, was perhaps first explored by Livingstone and colleagues[4)], who investigated the immersion of gloved hands in water of various temperatures. Driven by pragmatic occupational requirements, one group more fully developed that concept into a method

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of upper-limb cooling[5–8], such that it has become a preferred cooling method for clothed, hyperthermic workers[9–12]. In this project, the heat-loss potential of the hands and forearms was further investigated, but now with upper-limb cooling being studied following variations in exercise-induced, heat-storage rates that elicited equivalent deep-body (rectal) temperature elevations.

A methodological limitation that can occur within experiments of this nature involves the selection of a deep-body temperature index, against which cooling efficacy might be evaluated. Indeed, since the premise of all cooling methods is to reduce body-heat content as quickly as possible, then it is imperative that measurement phase delays do not introduce preventable sources of experimental error. Unfortunately, many applied physiologists choose to use a rectal temperature index to track changes in deep-body heat content. Whilst there are often good reasons for that choice, that site, along with most gastrointestinal sites, is known to be a heat-conduction dependent site with a significant thermal phase delay (6–60 min)[13, 14]. That time delay renders gastrointestinal sites as inappropriate during dynamic-phase experiments. Thus, during time-critical cooling trials, rectal temperatures are unable to provide meaningful data pertaining to the cooling rates of the central nervous tissues[15, 16]. To address that problem, an insulated auditory canal temperature was used in this experiment, since the vascular configuration of that region enables it to rapidly respond to changes in carotid artery[17], cardiac[18] and oesophageal temperatures[14], with a phase delay of ~2 min relative to oesophageal temperature[13, 14].

Subsequent research has not only replicated the thermal phase delays observed via the rectum during the whole-body cooling of hyperthermic individuals, but has also established a cutaneous vascular mechanism to explain those time-dependent observations[9]. Furthermore, that research group unequivocally demonstrated that the cutaneous vascular responses that accompany external cooling are powerfully influenced by the thermal state of the deep-body tissues prior to the initiation of external cooling[4, 20, 21]. Therefore, during hyperthermia, mild external cooling stimuli were found not to elicit the powerful vasoconstriction that was observed when similar stimuli were applied during normothermia. Instead, when the mean body temperature exceeds 38°C, hand blood flow is sustained at around 6 mL.100 mL^{-1}.min^{-1}, even when the hand is clamped at a water-cooled, skin temperature of 5°C[20]. That local blood flow approximates values observed during normothermia: 6.7 mL.100 mL^{-1}.min^{-1} (oesophageal temperature 37.0°C, mean skin temperature 33.6°C, hand skin temperature 33.4°C). Similar vascular responses are seen for the forearm during the cooling (5°C) of that segment[21], although the absolute flows were slightly lower than at the hand; 5.5 mL.100 mL^{-1}.min^{-1} for local cooling during whole-body hyperthermia, and 4.2 mL.100 mL^{-1}.min^{-1} when an identical cooling stimulus was applied to normothermic individuals. Therefore, in moderately hyperthermic individuals, the upper-limb retains its capacity to transport heat to the skin surface, even during strong, localised cooling that would otherwise have induced powerful cutaneous vasoconstriction.

Collectively, those observations provide a mechanistic explanation for the well-known effectiveness of upper-limb cooling in hyperthermic individuals, which had, to this point, only been established on theoretical grounds[8]. In the current investigation, that effectiveness was again explored, but now with an emphasis upon differences in heat extraction when passive, upper-limb cooling was applied following three different, exercise-induced rates of whole-body heating (light-, intermediate- and moderate-intensity treadmill exercise). All trials were terminated at a similar deep-body (rectal) temperature, so the rates of deep-body heating were dictated by the exercise intensities, which also determined the time for whole-body thermal equilibration and homogeneity to be achieved. Furthermore, those differences in work rate are accompanied by non-thermal variations in cutaneous vasomotor[22, 23] and sudomotor activity [24, 25], both of which can modify heat dissipation. On the basis of those physiological mechanisms, as well as possible differences in time-dependent, whole-body heat storage, it was assumed that heat extraction during recovery might differ among these trials. Accordingly, it was hypothesised that heat extraction accompanying upper-limb cooling would be faster following the highest work rate.

Methods

Participants

Eight healthy, young males with above average endurance fitness participated in this study (24 y [standard deviation {SD} 2], mass 74.9 kg [SD 7.2], height 176.4 cm [SD 8.1], peak aerobic power 3.9 L.min^{-1} [SD 0.61]). The procedures used during this experiment were approved by an authorised institutional committee, and were in compliance with the Declaration of Helsinki; the Institute of Review Board of the Seoul National University (IRB #. 2004/003-025). All subjects signed informed consent releases prior to participation.

Procedures

Experimental overview

The focus of this investigation was upon the speed with which heat could be extracted from moderately hyperthermic individuals using bespoke, water-perfusion sleeves that covered the forearms and hands, and through which cold water would be circulated. Whole-body heating was induced by participants walking and running at each of three speeds (Trial A 6 $km.h^{-1}$ [light exercise], Trial B 8 $km.h^{-1}$ [intermediate-intensity exercise] and Trial C 10 $km.h^{-1}$ [moderate exercise]), with participants completing those trials within a heated, climate-controlled chamber (33°C, water vapour pressure 3.52 kPa [70% relative humidity]). With the exception of one individual, who did not complete Trial B, participants completed all trials (Fig. 1). When deep-body temperature, as estimated from the rectum, reached 39°C, participants stopped running. Thus, the exercise duration was deep-body temperature limited. On satisfying that criterion, subjects immediately adopted a seated position on the treadmill and donned two water-perfusion sleeves, which were continuously perfused with cold water (6.3°C) during a resting recovery (20 min).

Experimental standardisation

Participants were asked to refrain from strenuous exercise, and the consumption of alcohol and tobacco for 24 h prior to each trial. They were also instructed not to consume any food or caffeine for at least 2 h prior to testing, and to arrive in a well-rested state. Rehydration drinks were provided following experimentation. On presentation, participants rested (30–60 min) and consumed 300 mL of water, after which experimental preparations commenced. Hydration status was then checked (urine specific gravity: PAL-10S, ATAGO, Japan) to confirm the required pre-experimental, euhydrated state, with water provided if urine specific gravity was >1.025. Subjects dressed into identical shorts, long trousers, socks and running shoes (combined mass without shoes: 340 g), all of which were provided, and used to simulate working clothes. To standardise metabolic heat production prior to commencing a trial, participants rested in a seated position on the treadmill (10 min) during preparation, and before commencing 10 min of resting (baseline) data collection.

Whole-body heating

Endogenous heating (metabolic heat production), in combination with a high ambient air temperature and water vapour pressure, was used to increase heat storage (Fig. 1). Those conditions were chosen to represent typical Korean summer conditions, and the work intensities averaged 41.6% (SD 9.4: light), 59.7% (SD 7.2: intermediate) and 67.3% (SD 11.7: moderate) of each individual's peak oxygen consumption. The three running speeds were used to elevate heat storage at different rates, although it was assumed that the faster heating rates would not be accompanied by even, whole-body distributions and equilibration of that thermal energy. In addition, whilst the exercise-related strain was estimated relative to each individual's peak aerobic power, when such exercise is performed in hot-humid conditions, the overall physiological strain is significantly greater.

Forearm and hand cooling

To simultaneously cool both forearms and hands at a constant rate, purpose-built, water-perfusion sleeves were manufactured. Those sleeves were designed for use in workplaces that might prevent upper-limb water immersion. Each sleeve consisted of an inner mesh layer of nylon-spandex (85% nylon and 15% polyurethane) and an outer, flexible polyester layer (92% polyester and 8% polyurethane). Into the gaps between the two layers of each sleeve, 4 m of PVC tubing was inserted (4 mm internal diameter and 6 mm external diameter), and threaded through the woven mesh to keep it securely positioned, such that it remained in close skin contact when worn. The sleeves were donned as soon as possible after exercise ceased, and a 20-min recovery commenced. Water pumped through the sleeves was cooled to a mean inlet temperature of 6.3°C (SD 0.2; RW-0525G, JEIO Tech., Korea).

Measurements

Deep-body temperatures were measured continuously (5-s intervals), and simultaneously from two sites: an insulated auditory canal (LT-ST08-11, Gram Corporation, Japan) and the rectum[26] (16 cm beyond anal sphincter; LT-ST08-11, Gram Corporation, Japan). The auditory canal responds rapidly to intra-thoracic temperature changes[13, 14], whilst rectal temperatures have a significant thermal phase delay[13, 14], yet that site is often used as a measure of choice in many applied settings. Skin temperatures were also measured continuously (5-s intervals) using thermistors (LT-ST08-12, Gram Corporation, Japan) secured to nine sites with a single layer of adhesive tape (Micropore surgical tape, 3M, U.S.A.): forehead, left chest, central abdomen, left forearm, left dorsal hand, third finger left hand, left anterior thigh, left posterior calf and left dorsal foot. All

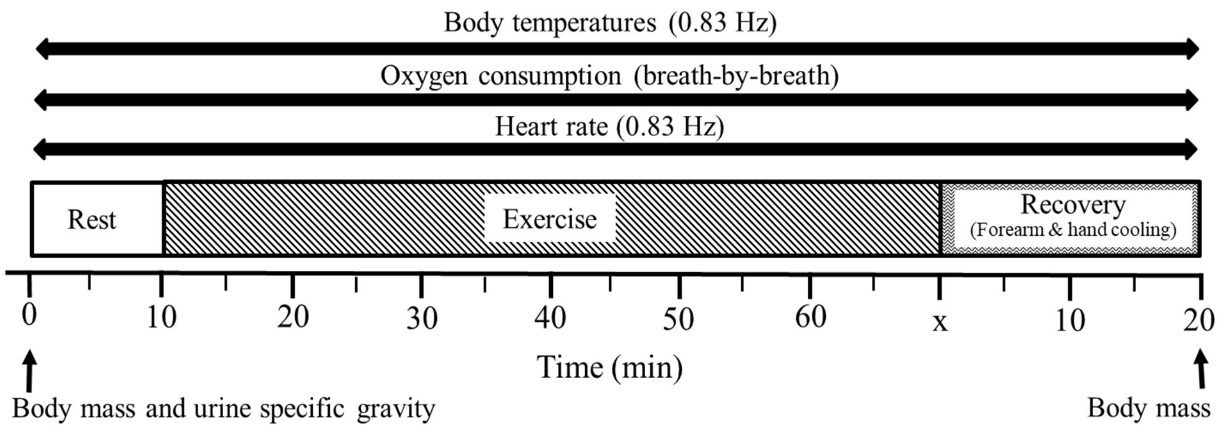

Fig. 1. An overview of the experimental design. The arrows indicate times of continuous (horizontal) or time-locked data collection. Every trial followed the same sequence, with between-participant time differences only occurring during the exercise phase, which was aimed at gradually elevating deep-body temperature to a moderately hyperthermic state (rectal temperature 39.0°C).

temperatures were collected using a data logger (LT-8A, Gram Corporation, Japan). Mean skin temperature was derived using a modified Hardy and DuBois equation[27]. Three of those skin sites were located below one of the cooling sleeves (left forearm, left dorsal hand and third finger of the left hand).

To estimate heat extraction through each water-perfused sleeve, inflowing and outflowing water temperatures were measured every 10 s using thermistors positioned within the corresponding water lines (LT-ST08-12, Gram Corporation, Japan). Those data were recorded using another data logger (LT-8A, Gram Corporation, Japan). Heat extraction was approximated using the following calculation[28].

Heat extraction = mass flow × specific heat × temperature difference *Equation 1*

where:

heat extraction = removal of thermal energy from the skin ($J.min^{-1}$)

mass flow = water flow through the sleeve ($L.min^{-1}$)

specific heat = specific heat of water (4.186 $J.g^{-1}.^{o}C^{-1}$)

temperature difference = difference between inflowing and outflowing water temperatures (°C).

Oxygen consumption (open-circuit respirometry) was measured using an automated system (Quark CPET, COSMED, Italy), with expired gas fractions and expiratory flows sampled continuously (breath-by-breath) from a correctly fitted face mask (C04324-10, COSMED, Italy). Two-point gas (room air plus alpha standard gases [16.00% oxygen, 4.00% carbon dioxide, 80% nitrogen]) and a range of physiologically relevant flow calibrations preceded data collection. Heart rates were recorded from ventricular depolarisation using a chest-strap transmitter (5-s intervals; RC3 GPS, Polar Electro, Finland). Whole-body sweat rate was estimated from changes in body mass, which was measured in a semi-nude state on a calibrated scale before and after the experiment (ID2, Mettler-Toledo, Germany: ± 1 g). Those masses were not corrected for respiratory water loss, and urination did not occur.

Data analysis

This experiment was based upon a repeated-measures design, with subjects acting as their own controls, and participating in all trials. After testing for normality and sphericity, between-trial comparisons were performed using either one-way repeated measures Analysis of Variance, or Friedman's test for comparisons among the three conditions. To isolate sources of significant differences, pairwise, *post hoc* comparisons were performed. Data are reported as means with standard errors of the means (SE) and standard deviations (SD) for describing data distributions. Statistical analyses were undertaken using SPSS software (v.23.0), with *alpha* set at the 0.05 level.

Results

Physiological baselines

During seated rest, prior to commencing exercise, baseline oxygen consumption, heart rates and tissue temperatures were not significantly different from one another across the three trials (Table 1; $p>0.05$). Whilst those data are consistent with values expected from healthy, well-

Table 1. Physiological variables during the three stages of each exercise trial (*N*=8).
Note: Between-trial differences took the form of variations in exercise intensity, with subjects walking (light: 6 km.h^{-1}), slowly jogging (intermediate: 8 km.h^{-1}) and running (moderate: 10 km.h^{-1}). Data were averaged over 10 min of seated rest (baseline), the last minute of exercise and the final 5 min of recovery. Data are means with standard errors of the means in parenthesis. Significant differences are shown using the following symbols (p<0.05): † (light versus intermediate), ‡ (light versus moderate) and § (intermediate versus moderate).

Stage	Variables	Light	Intermediate	Moderate
Baseline	Oxygen consumption (mL.min^{-1})	404 (26)	431 (37)	383 (16)
	Heart rate (b.min^{-1})	76 (3)	75 (2)	75 (3)
	Auditory canal temperature (°C)[a]	36.3 (0.2)	36.0 (0.1)	36.0 (0.2)
	Rectal temperature (°C)	37.0 (0.1)	36.9 (0.1)	37.0 (0.1)
	Mean skin temperature (°C)	34.3 (0.1)	33.9 (0.5)	34.5 (0.1)
	Finger temperature (°C)	35.5 (0.1)	35.5 (0.1)	35.4 (0.1)
Exercise	Oxygen consumption (mL.min^{-1})	1,589 (70)†,‡	2,398 (130)	2,631 (53)
	Heart rate (b.min^{-1})	166 (4)†,‡	177 (5)	184 (4)
	Auditory canal temperature (°C)	38.2 (0.2)	37.9 (0.3)	37.9 (0.1)
	Rectal temperature (°C)	38.8 (0.1)	38.9 (0.1)	38.8 (0.1)
	Mean skin temperature (°C)	37.0 (0.3)	37.1 (0.3)	36.9 (0.4)
	Finger temperature (°C)	36.7 (0.4)	36.9 (0.5)	36.8 (0.6)
Recovery	Oxygen consumption (mL.min^{-1})	527 (28)	576 (56)	601 (28)
	Heart rate (b.min^{-1})	121 (5)	119 (5)	121 (4)
	Auditory canal temperature (°C)	37.9 (0.3)	37.7 (0.2)	38.1 (0.1)
	Rectal temperature (°C)	38.7 (0.1)‡	39.0 (0.1)	39.2 (0.1)
	Mean skin temperature (°C)	36.0 (0.3)	36.3 (0.3)	36.2 (0.5)
	Finger temperature (°C)	33.5 (0.4)	35.0 (0.7)	33.9 (1.2)

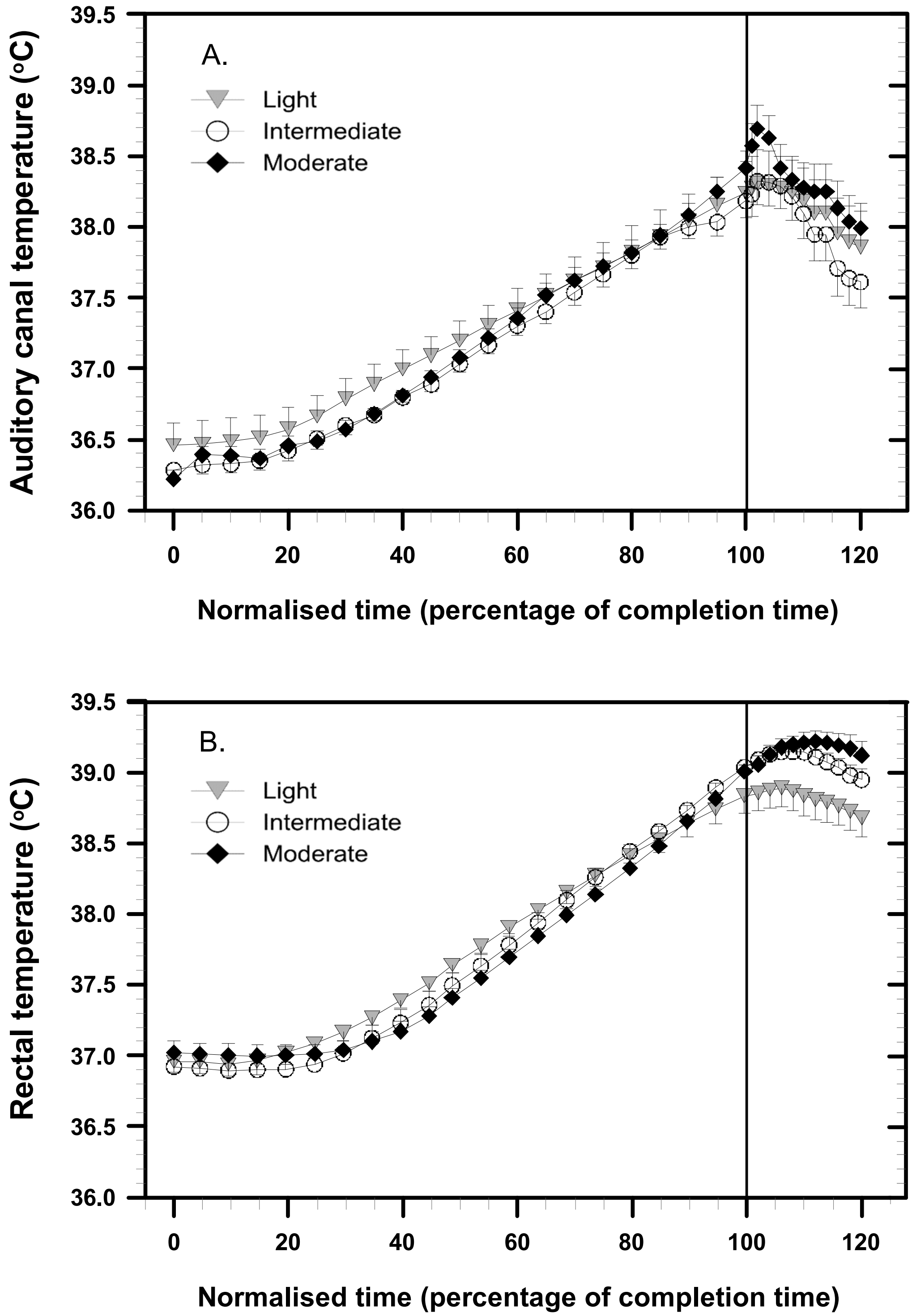

Fig. 2. Auditory canal (Fig. 2A) and rectal temperatures (Fig. 2B) during exercise-induced, whole-body heat storage, and during the post-exercise cooling of the upper limbs using water-perfused sleeves. Data are means (with standard errors of the means) for three exercise intensities: light (6 km.h^{-1}), intermediate (8 km.h^{-1}) and moderate (10 km.h^{-1}). The time axes have been normalised to the participant-specific trial completion times, which were determined by the time taken for the rectal temperature to reach 39.0ºC (Fig. 2A: *N*=8 for the light and moderate conditions, *N*=7 for the intermediate condition; Fig. 2B: *N*=8 for all conditions).

rested individuals, it is noted that, since subjects rested in a heated climate chamber, slight elevations in heart rate and tissue temperatures were observed. An initial rise in auditory canal temperature was seen, with thermal stabilisation attained towards the end of the rest period. That elevation is normal, since it is influenced by the ambient conditions, with that influence producing a thermal bias that needs to stabilise before commencing data collection[13]. From these observations, one may conclude that artefacts unrelated to the experimental treatments existed during either the exercise or the post-exercise cooling periods.

Metabolic heat production

Exercise ceased when the rectal temperature reached 39.0ºC, or at volitional exhaustion; the latter happened in two intermediate trials and one moderate-exercise trial. As predicted, those durations were inversely related to the exercise intensity: light 70.7 min (SE 6.4), intermediate 42.6 min (SE 1.5) and moderate 34.4 min (SE 1.4). The duration of the light exercise period was significantly longer than the other two trials ($p<0.001$), but the intermediate and moderate durations were not significantly different ($p>0.05$). Data for oxygen consumption, heart rate, and the deep-body and skin temperatures are contained in Table 1. By design, oxygen consumption and heart rate increased with increments in the work rate. Whole-body sweat rates also differed: light 11.1 g.min^{-1} (SE 0.5), intermediate 15.3 g.min^{-1} (SE 1.2) and moderate 15.4 g.min^{-1} (SE 1.5). During the light-intensity exercise, sweating was significantly lower than both of the other trials ($p<0.05$), but differences between the intermediate and moderate intensities were non-significant ($p>0.05$).

Fig. 2 shows the combined exercise- and heat-induced changes in auditory canal and rectal temperatures during steady-state exercise and recovery. At the cessation of exercise, within-site differences in deep-body temperature did not differ significantly across the three trials (Table 1; $p>0.05$). When those data were normalised to the finishing time of each person, deep-body heating appeared to be equally rapid and uniform across those trials. However, whilst those temperatures reached approximately the same point at the same relative time, those deep-body tissues were not heating equally fast. Indeed, as one would predict, the speed of deep-body heating was directly related to the exercise intensity, and that outcome was also apparent at the rectum. Thus, the apparent equality of the heating rates shown in Fig. 2 was an artefact of normalisation, with auditory canal temperatures climbing at average rates of 0.03ºC.min^{-1} (SE<0.001; light exercise; derived from the ratio of the change in temperature to the change in time), 0.05ºC.min^{-1} (SE<0.001; intermediate) and 0.07ºC.min^{-1} (SE<0.001; moderate). Each of those local thermal sensitivities differed significantly from one another (all $p<0.05$).

Similarly, mean skin temperatures were equivalent across the three conditions at the end of exercise (Table 1; $p>0.05$). Forearm, hand and finger temperatures reflected trends seen within the mean skin temperature. Significant differences within each of those measurement sites, and among the three conditions, were not evident at the end of exercise (Table 1; forearm: 35.9ºC [SE 0.3; light], 36.0ºC [SE 0.3; intermediate] and 36.6ºC [SE 0.3; moderate; $p>0.05$); hand: 36.0ºC [SE 0.3; light], 35.1ºC [SE 1.0; intermediate] and 36.1ºC [SE 0.4; moderate; $p>0.05$]).

Heat extraction

The rate of heat extraction through the liquid-cooling sleeves during recovery did not differ among the three treatments: -11.2 W (SE 0.5; light), -11.8 W (SE 0.6; intermediate) and -12.3 W (SE 0.5; moderate; $p>0.05$). When those data were integrated over the entire recovery duration, an identical outcome was observed, with heat removal averaging 150 kJ (SE 6; light intensity), 158 kJ (SE 13; intermediate) and 163 kJ (SE 6; moderate; $p>0.05$). As a consequence, the working hypothesis for this experiment was not accepted.

That outcome during recovery was reflected within the auditory canal data (Fig. 3), which responded rapidly to the cooling treatment, although a thermal overshoot was evident following the heaviest exercise stimulus. The respective auditory canal cooling rates for the three trials were 0.03ºC.min^{-1} (SE 0.004; light exercise), 0.04ºC.min^{-1} (SE 0.004) and 0.05ºC.min^{-1} (SE 0.004; moderate). Differences between the cooling rates following light and moderate exercise approached statistical significance ($p=0.06$).

That same outcome during cooling was not evident within the rectal temperatures (Fig. 3), which displayed a consistent and more protracted thermal after-rise during recovery from both the intermediate- and moderate-intensity exercise periods, such that during the last 5 min of recovery, the rectal temperatures for those trials still remained elevated, and did not significantly differ from the corresponding values recorded at the end of exercise (Table 1; $p>0.05$). Indeed, those temperatures were >1ºC above the corresponding auditory canal temperatures (Table 1). That after-rise was predictable, and apparent at both sites (Fig. 3). However, it was both transient and negligible for the auditory canal temperatures.

Discussion

The principal focus of this research was on passive heat removal from hyperthermic individuals using upper-limb (forearm and hand) cooling. Of particular interest, was whether or not the rate of heat storage, prior to the initiation of cooling, would influence that heat-extraction rate, either through exercise-induced differences in the activation of physiological cooling mechanisms, or through time differences taken to establish a whole-body thermal equilibrium. For the experimental conditions used in this project, and from the results so derived, it is evident that the post-exercise cooling rate appears to be independent of the time taken, and the work rate used to heat the deep-body tissues. The evidence supporting that interpretation includes the equivalence of both the heat extraction data and the auditory canal cooling rates (Table 1, Fig. 3). Those outcomes conform with the principles of thermodynamics (heat-transfer law[29] and the heat conduction equation[30]). That is, the cooling rate is simply a function of the temperature difference between the heat source (the participants) and the heat sink (water within the cooling sleeves). Therefore, the working hypothesis was not accepted.

It is worth briefly considering why the two deep-body (core) temperature indices sometimes provided apparently equivalent, but at other times, clearly opposing information. For this, we need to consider another principle of thermodynamics; the Zeroth Law of Thermodynamics. We use sensors to measure the temperatures of many things, and, assuming that our sensors are correctly calibrated, each of those measurements will be valid. However, in physiology, we cannot always measure the temperature of the body tissues or organs in which we have an experimental or clinical interest. To solve that problem, we measure the temperature of a surrogate site, and then either assume, or take the necessary steps to ensure, that the surrogate site is at the same temperature as the site of interest. Therefore, the sensor, the surrogate site and the site of interest must all be in thermal equilibrium. If that state does not obtain, then our surrogate measure will be physiologically invalid.

Now consider the rectum and the external auditory meatus. Heat transfer, and therefore thermal equilibration, of the former is conduction dependent, and is rather slow. Indeed, depending upon the experimental conditions, the thermal inertia of the rectal tissues means that site can take from 6–60 min to fully respond to rapidly changing temperatures in other deep tissues[13]. This thermal inertia is seen in Fig. 3, and it means that, whilst those temperatures are truly rectal temperature, they are conveying no meaningful information concerning the thermal state of critical body tissues beyond the rectum. This validity problem also pertains to measures of gastrointestinal temperature, and unless it can be proven that rectal temperatures provide valid surrogate temperatures for heat-sensitive intestinal tissues, then the relevance of that index to rest of the gastrointestinal tract must also be questioned.

Given that much applied research is driven by work-related considerations, in this case the cooling of hyperthermic individuals in the workplace, then it is worth considering how the current results might influence workplace treatments. In the first instance, additional evidence has been provided to support the efficacy of upper-limb cooling, as first described[5–8], and then followed, by others[9, 12, 31, 32]. However, since it would be expected that water immersion would be more effective than the perfusion-garment method, due to both the size of the treated surface area and the closeness of the skin contact, then one must exercise caution when comparing experiments that involved different upper-limb cooling methods. Moreover, due to the use of different indices of deep-body temperature, comparisons across methods with different phase delays should not be undertaken. Secondly, the evidence from this experiment shows that neither work intensity nor the time taken to reach a state of moderate hyperthermia seem to influence post-exercise cooling rates. This information simplifies the use of this procedure as a prophylactic measure. Thirdly, given that the slowest cooling rate was 0.03°C.min^{-1} when using water at 6.3°C, then to achieve a 1°C reduction in deep-body temperature, a cooling duration of at least 33 min is required when using water at that temperature when perfusion sleeves are used, although it will be faster if water immersion is used. Fourthly, further evidence has been presented to show that it is invalid to use rectal temperatures in dynamically responding thermal states. Thus, even though that may be the only index available in the field, it may not provide either meaningful or clinically useful information.

Conclusions

From this experiment, two conclusions can be drawn. Firstly, heat extraction from moderately hyperthermic individuals, using upper-limb (forearm and hand) cooling, appears to be equally rapid, regardless of how fast heating occurred, providing those people attained the same level of

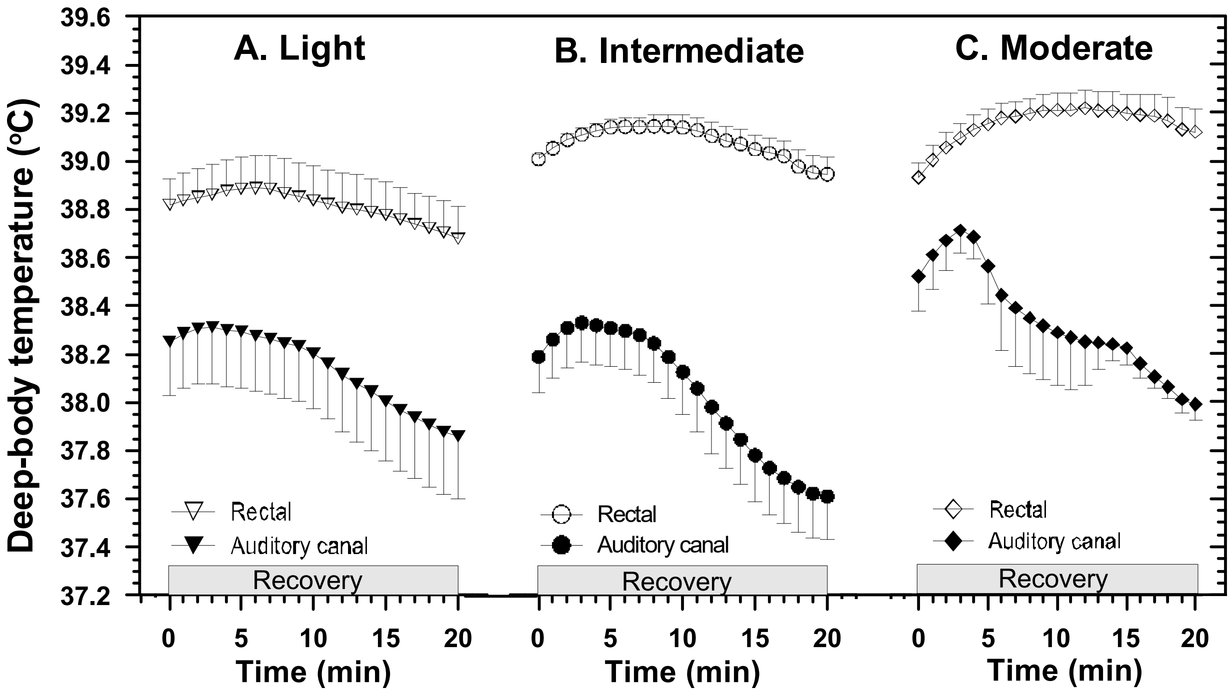

Fig. 3. Deep-body (auditory canal and rectal) temperatures during post-exercise recovery and passive cooling of the upper limbs using water-perfused sleeves. Data are means (with standard errors of the means) for trials completed at three exercise intensities: light (Fig. 3A: 6 km.h^{-1}), intermediate (Fig. 3B: 8 km.h^{-1}) and moderate (Fig. 3C: 10 km.h^{-1}). The abscissae show recovery times during (passivepper-limb cooling, following the attainment of a rectal temperature of 39.0°C, with sample sizes shown in Fig. 2.

hyperthermia prior to treatment. Secondly, due to the thermal inertia of the rectal tissues, rectal temperatures will not yield either meaningful or useful information when used in combination with rapidly changing thermal states.

Acknowledgments

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Conflict of Interest

There are no conflicts of interest.

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