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Controlling rectal and muscle temperatures: Can we offset diurnal variation in repeated sprint performance?

Controlling rectal and muscle temperatures: Can we offset diurnal variation in repeated sprint performance?

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Abstract

We investigated whether increasing morning rectal temperatures (T_{rec}) to resting evening levels, or decreasing evening T_{rec} or muscle (T_m) temperatures to morning values, would influence repeated sprint ability (RSA) in a causal manner. Twelve trained males completed five sessions: control morning (M, 07:30 h) and evening (E, 17:30 h) sessions (5-min warm-up), and then three further sessions – a warm-up morning trial (M_E, on a motorised treadmill) until T_{rec} reached evening levels; two cool-down evening trials (E_{MR} and $E_{MM,}$ in 16-17°C water) until T_{rec} or T_m values reached morning temperatures, respectively. All sessions included 3x3-s task-specific warm-up sprints, thereafter 10x3-s repeated sprints with 30-s recoveries were performed a non-motorised treadmill. T_{rec} and T_m measurements were taken during the protocol. Values for T_{rec} and T_m and distance covered-per-sprint, average speed and power were all higher in the evening than the morning (0.45°C and 0.57°C; and a range of 9-10%, $P<0.05$). Pre-cooling T_{rec} and T_m in the evening significantly reduced RSA variables to M-condition values. However, an active warm-up had no effect on performance. The diurnal variation in T_{rec} and T_m cannot fully explain time-of-day oscillations in RSA; the exact mechanism(s) for a causal link between temperature and performance are still unclear.

Introduction

In male participants in a temperate environment (around 17-20°C), many human performance variables display diurnal variation [1]. Repeated-sprint ability (RSA), defined as the ability to produce the best possible short-term performance over a series of sprints (<6 s) with minimal recovery intervals (<60 s) between bouts [2], an important component of team-sports performance [2, 3, 4]. As far as we are aware, only one study has investigated the effects of time of day on RSA on a non-motorised treadmill - an apparatus that provides a more externally valid mode of measurement for RSA in most team sports rather than a cycle ergometer. Pullinger et al. [5] reported in a population of 20 trained male participants, who were familiarised with the protocol about 5 times - distance covered, peak and average power, peak and average speed - all showed significantly higher values in the evening compared to the morning (a range of 3.3-8.3%).

The exact mechanisms for this observed diurnal variation in human performance are still unknown but have been attributed to a number of factors [5, 6]. One factor which has been proposed is the causal link due to the temperature rhythm, which might be implicated directly or indirectly, where the higher evening resting core body temperature (~0.8°C in rectal and gut sites [7]) and local muscle temperature (~0.35°C in vastus lateralis at depths of 3 cm, [6, 8]) produce an increase in force-generating capacity of the muscle [9, 10] and neural function (reduced twitch time-course or increase in speed of contraction, [11]). However, routinely athletes have to compete or undergo training in the morning when they are biologically weaker; normally in competition heats or quarterfinals to get through to the finals scheduled in the evening (such as in the London 2012 Olympics scheduling for swimming). If the causal link that has been proposed between core and muscle temperature and diurnal variation in performance were simple, we could offset diurnal variation with a suitable warm-up. The link between core temperature and performance has been studied mainly in two ways. The first link, which has received some interest in the literature, involves using either active (by means of exercise) or passive (by means of a chamber or water bath) "warm-ups" to increase rectal body temperature in the morning to approximately, or in some cases precisely, the resting temperature found in the evening, and examining whether this increases morning performance to evening levels (using cycling or swimming time-trials or muscle force production; see [6] for further details). The second link, which has received far less attention so far, explores whether pre-cooling rectal temperature in the evening to values similar to, or exactly equal to, those observed in the morning, results in a parallel decrease in performance to morning values. To our knowledge, only two studies have sought to investigate the effect of core temperature on performance (isometric and isokinetic knee extension and flexion) with precise modelling of pre-performance rectal temperature and time of day interaction. These studies reported that cooling the core decreased performance to morning levels but that there was no effect when warming the core in the morning to evening levels [8]). Lastly, the contribution and importance of T_{rec} and/or T_m to this drop in performance with cooling has yet to be unpicked. Therefore, aim of the present study is to modulate rectal or muscle temperature to investigate whether increasing morning rectal temperature (by an active warm-up) to evening resting values or decreasing evening rectal and/or muscle temperatures (by immersion in a cool bath) to morning resting values leads to a change in RS performance on a non-motorised treadmill in well-trained, familiarised and highly-motivated participants.

Methods

Participants

Twelve well-trained male participants (mean ± SD: age 21.7±2.6 Years, maximal oxygen uptake ($\dot{V}O_2$ peak) 60.6±4.6 mL·kg^{-1}min^{-1}, height 1.78±0.07 m, body mass 76.0±6.3 kg respectively, were recruited for this study. The study was ethical approved by the University Ethics Committee and the authors confirm that the study was conducted in accordance with the Declaration of Helsinki and meets the ethical standards of the International Journal of Sports Medicine [12];

Protocol and measurements

All sessions took place under standard laboratory conditions (lighting, room temperature and humidity, and barometric pressure were 200-250 lux, 21.1±1.1°C, 34.6±5.1 %, and 755.3±6.6 mmHg, respectively). Participant completed five familiarization sessions each separated by at 48 h, thereafter each participant completed five experimental sessions separated by three days: a morning and an evening trial (07:30 and 17:30 h; M and E) after a standardized 5-min warm-up at 10 km·h^{-1} on a motorized treadmill (Pulsar, H/P cosmos, Germany) which were counterbalanced in order of administration; an active warm-up morning trial (M_E, at 10 km·h^{-1} on a motorized treadmill); and two passive cool-down evening trials (E_{MR} and E_{MM}, at 16-17°C [Hitema ECA.002 water chiller, TO1B2620, Italy] in a water immersion bath where they semi-reclined immersed up to their neck [E_{MR}]or waist [E_{MM}), respectively) that were also administered in a counterbalanced design to minimize any learning or order effects [1]. In the M_E session, starting rectal temperature (T_{rec}) was modelled to become equal to that found in the participant in the previous E session at rest. In the E_{MR} and E_{MM} sessions, starting T_{rec} and muscle (T_m) temperatures were modelled to become equal to those found in the individual in the previous M session at rest. Participants' T_{rec} and T_m were again measured when they mounted the treadmill (after towel drying) and they then commenced the rest of the experimental protocol.

The participants were free to live a "normal life" between sessions, sleeping at home at night, and attending lectures and doing light office work in the day. They were told to refrain from drinking alcoholic or caffeinated beverages and from other training or heavy exertion for the 48 h before the experiments or during them and retire at 23:30 h and waking at 06:30 h to be in the laboratory for 07:00 h. Participants recorded the type, amount and timing of the food they ate for the period of 24 h before and taken during the day of the experimental session and replicated this for experimental conditions. For the morning sessions, participants arrived in a fasted state and were asked not to eat in the 4-h prior to the evening session. A schematic of the protocol is given in Figure 1. Participants arrived 1-h before the start of the test, inserted a soft flexible rectal probe (Mini-thermistor; Grant instruments Ltd, Shepreth, UK) ~10 cm beyond the external anal sphincter and then lay down and relaxed in the laboratory. Rectal temperature (T_{rec}) was then recorded continuously for the last 30-min by means of a Squirrel 1000 data logger (Grant Instruments) while participants remained semi-supine but awake. The average value of the last 5-min recording was defined as resting T_{rec} and used for subsequent analysis. At this time 'resting' muscle temperature (T_m) was assessed using a needle thermistor inserted into the right leg vastus lateralis (13050, ELLAB, Hilleroed, Denmark). The area was marked with a permanent marker so as to minimize site variation between testing sessions. Thigh skinfold thickness was measured using Harpenden skinfold callipers (HSK BI, West Sussex, UK) and halved to determine the thickness of the thigh subcutaneous fat layer over the participant's vastus lateralis [13]. The needle thermistor was then inserted a depth of 3 cm plus one-half the skinfold measurement for determination of deep T_m (in compliance with procedures set out by 14, 15). Muscle temperature was recorded using an ELLAB electronic measuring system (CTF 9004, ELLAB, Denmark).

The participants then undertook a standardized 5-min warm-up at 10 $km \cdot h^{-1}$ on a motorised treadmill. A second T_m measure was assessed following the warm-up. Repeated sprint performance was performed on a non-motorized treadmill (Woodway Force 3.0; WI, USA). The exact protocol has been described previously, where individuals sprint for 3 s x 10 times with 30 s recovery between sprints [5]. During the test, treadmill speed, power output and distance covered were sampled at a rate of 200 Hz, leading to 600 samples per variable over the 3-s sprint. Sprint data for peak power (PP), average power (AP), peak speed (PS), average speed (AS) and distance covered (DC) were recorded with a commercially-designed software program (Pacer Treadmill Software; Innervations, Australia) and used in the subsequent analysis. Fatigue was calculated using the % decrement method as advised by Glaister et al. [16] see equation below:

Fatigue = [100 x (total *Y*/ideal *Y*)] – 100 [17].

Where: *Y* = peak speed or peak power; total = sum of *Y* for all sprints; ideal = the number of sprints (10) x the highest value for *Y*.

During all sessions, participants undertook a task-specific warm-up procedure, consisting of 3 x 3 s sprints at 50, 70 and 80% of perceived maximum effort, respectively. The task-specific bursts of activity were brief enough not to cause significant fatigue. Standardized strong verbal encouragement was given during all familiarization and experimental sessions.

Statistics

The data were analyzed using the Statistical Package for Social Sciences (SPSS) for Windows (IBM version 20, Chicago, IL, USA), with significance set at $p \leq 0.05$. Data were checked for normally distribution and if so were analysed using a General linear model with repeated measures for all variables. Graphical comparisons between means and Bonferroni pairwise comparisons were made where main effects were present. The results are presented as the mean ± the standard deviation (SD) throughout the text unless otherwise stated. Ninety-five percent confidence intervals (CIs) are presented where appropriate.

Results

Rectal and muscle temperature at rest

Rectal Temperature (T_{rec}): There was a significant diurnal variation for T_{rec}, with higher resting values in the E *vs.* the M condition (CI = 0.27-0.62°C $P<0.0005$: Table 1 and Figure 1). This variation was consistent and in the expected direction for resting values for T_{rec} for the other conditions (E_{MR} *vs.*M +0.44°C; E_{MM} *vs.* M +0.46°C; E *vs.* M_E +0.40°C; E_{MR} *vs.* M_E +0.39°C; E_{MM} *vs.* M_E +0.41°C). There was no statistical difference between resting T_{rec} levels in the morning (07:30 h) for M or M_E condition; and T_{rec} levels in the evening (17:30 h) for E, E_{MR} or E_{MM} conditions ($P>0.05$). *Muscle temperature:* T_m values at a 3-cm depth were higher in the evening (E, E_{MR} or E_{MM}) conditions than the morning condition (+0.54°C, +0.73°C and +0.69°C; $P<0.05$) and M_E condition (+0.54°C, +0.73°C and +0.69°C; $P<0.05$). There was no difference between any values for any other conditions ($P>0.05$; Table 1).

Rectal and muscle temperature after warm-up or cool down (before RSA).

Rectal Temperature (T_{rec})*:* T_{rec} post warm-up values for M_E, E and E_{MM} were higher than M (+0.33°C, +0.38°C and +0.22°C; P<0.05) and E_{MR} (+0.45°C, +0.49°C and +0.33°C; P<0.05, see Table 1 and Figure 2) conditions. Pairwise comparisons showed M values to be higher than E_{MR} values (+0.45°C; P=0.032). Further, M_E and E_{MR} values were exactly the same as resting E and M condition values, respectively. In summary, the protocol produced the changes in T_{rec} (to resting values previously observed in the morning and evening) that were required to test the basic research questions. There was no difference between any values for any other conditions (P>0.05). *Muscle temperature:* T_m values at 3 cm were lower in the E_{MM} condition than the M, M_E, E and E_{MR} conditions (-3.36°C, -3.76°C, -3.71°C and -1.90°C; P<0.05, see Table 1). Pairwise comparisons showed M, M_E and E values to be higher than the E_{MR} condition after the cool down (+1.46°C, +1.86°C and +1.81°C; P<0.05). Further, E_{MM} values were nearly exactly the same as the resting M condition T_m values at 3 cm depth (+0.01°C). There was no difference between any values for any other conditions (P>0.05). In summary, the protocol produced the changes in T_m at a 3-cm depth (to resting values previously observed in the morning) that were required to test the basic research question.

Repeated Sprint Ability (RSA) measures: Table 1 shows the group means (±SD) for all RSA variables recorded in each condition with statistical analyses. There were time-of-day effects for distance covered (DC), average speed (AS) and average power (AP) with higher values in the E condition than the M condition (9.0-10.2%; P<0.05; see Figure 2 and Table 1). All other measures of RSA (such as PP, PS, % decrement for power and speed) were not significantly different between M and E conditions. The active warm-up strategy (M_E) in the morning did not significantly increase any RSA values. Pre-cooling core (E_{MR}) in the evening significantly reduced all RSA variables except for percentage decrements for power and speed, all of which reported significantly higher values in the E (8.5-15.5%) and M_E (8.9-12%) conditions than the E_{MR} condition (P<0.05; see Figure 3 and Table 1). Further, E_{MR} values for PS were significantly lower than E_{MM} condition (P<0.05). Pre-cooling muscle (E_{MM}) in the evening also significantly reduced all RSA variables except for PP, PS and percentage decrements for power and speed, all of which reported significantly higher values in the E condition than the E_{MM} (8.8-9.5%; P<0.05; see Figure 3 and Table 1) condition. There was no difference between any values for any other conditions (P>0.05). There was no significant sprint effect, nor interaction between sprints and condition (P>0.05).

***** Insert Figure 1 and 2 and Table 1 and 2 near here*****

Correlations between measured variables

Correlations between the measured variables are shown in Table 2. Important findings were: there were significant positive correlations between T_{rec} and T_m (at 3 cm), between T_{rec} and RPE, TC and all measures of RS performance. Similarly, there were significant positive correlations between T_m and RPE, TC and most measures of RS performance (Average and peak speed, peak power and distance covered). However, there were no significant correlations between fatigue indices for peak power output or peak speed, or effort and T_{rec} or T_m.

Discussion

The main aim of the study was to investigate if modulating T_{rec} and/or T_m values leads to a change in the normal morning-evening difference in RS performance. The main findings of the study were: 1) under normal circumstances, distance covered per sprint, average speed and average power were significantly greater in the evening than the morning (~9-10%; See Table 1 and Figure 2), agreeing with our past work [5]; 2) increasing morning T_{rec} by an active warm-up to exactly that found in the evening, a rise of 0.40°C, did not result in RSA becoming equal to evening values (see Figure 1); 3) Decreasing evening T_{rec} by a passive cool-down to exactly that found in the morning at rest, a drop of 0.40°C, resulted in a decrease in RS performance that was not statistically significantly different from morning values but was significantly lower than the E and M_E sessions (a drop of 8.5-15.5% and 5.8-10.4%; see Figure 2 and Table 1); and 4) Decreasing evening T_m by a passive cool-down to exactly that found in the morning at rest, a drop of 0.70°C, resulted in a decrease in RSA that was not statistically significantly different from morning values (a drop of 3.4-9.5%; see Figure 2). To the best of our knowledge, this is the first study to demonstrate these results, with precise modelling of pre-exercise temperature (by removing individuals from the warming or cooling stimulus when the required T_{rec} or T_m was reached). Using a warm-up (active or passive) or cool-down of standard duration, as used by others [18, 19, 20, 21], produces large variation in core and/or muscle temperatures within individuals, either resulting in over- or under-shooting the required value. It was observed that variation in the time taken to reach the required temperatures differed between participants and conditions (9:48±3:46 min:s for M_E, 20:46±11:51 min:s for $E_{MR,}$ 6:55±6:10 min:s for E_{MM} respectively.

Passive whole-body pre-cooling (by air, a water bath, water-perfused suits or by showering) lowers T_{rec} and T_m, which has been shown to decrease neuromuscular function [22, 23], further, muscle force production of the left knee extensor and jump height is greatly reduced following leg immersion in a cold bath [24, 25]. It has been shown that T_m has a dose-dependent relationship for cycle sprints (over a range of 36-41°C [26]), whole-muscular performance (over a range of 29.5-33.5°C [27, 28]) and Isokinetic and isometric leg extension (36.7-37.4°C [8]). In all cases, the rate of deterioration in muscle performance was linked to decreasing muscle temperature [23]. This relationship seems to be somewhat dependant on factors such as speed of contraction, type of exercise, time on task and the degree at which body temperature decreases. In our study in the E_{MM} condition, the range of T_m after cooling (34.0-36.6°C), equalled that of the M condition at rest, resulting in RSA performance being significantly different from those found in the E condition for all variables, but no different between the M and M_E conditions. Further, following the E_{MR} condition, the range of T_m after cooling in our study (mean of 33.8°C with a range of 32.1-35.1°C) was significantly lower than values found in any of the other conditions and resulted in a significant decrease in the majority of RSA variables (see Table 1), when compared to the other 4 conditions. It has previously been stated that, in order for T_m to affect muscle performance (peak torque), a critical threshold of <34.0°C is required. However, with regard to RS performance, we disagree with those findings, as we found RSA performance to be affected from values of 35.7°C and below. The mechanisms regarding how and why subnormal muscle temperatures affect RS performance (muscle performance) have been reviewed previously (8, 23, 29). These reasons are believed to be: 1) Cooling muscle alters co-activation as well as reduces the activity of muscle spindles; 2) Cooling muscle affects the relationship between force production and speed, therefore maximal power output and force production in a cooled muscle occur with slower muscle contraction velocity than at normal temperatures; 3) Muscle contractile properties are sensitive to temperature, with the rate of contraction significantly slower and essentially leading to less powerful contractions; and 4)

Electrical activity of muscle might be substantially reduced by cooling. This results in a decrease in nerve conduction velocity that is proportional to the amount of cooling [22, 30].

Taken together, the results of this study support the view that morning-evening differences in RSA, when diurnal variation in core and deep muscle temperatures (3 cm) are evident, do not depend only on muscle temperature (in accord with the views of others [22, 30]. but also to other factors, possibly the environment and the body clock (endogenous factors). Therefore, our findings are in agreement with those previously published where an active warm-up in the morning to reach resting evening T_{rec} levels did not offset diurnal variation but a passive cooling-down in the evening to reach resting morning T_{rec} levels did offset performance to morning levels [31, 12]. This anomalous result further highlights the different physiological mechanisms involved in cooling versus warming core and muscle temperatures and the effects of this on RS performance [23].

Conclusion

In this highly motivated population, raising morning rectal temperatures to evening values by active warm-up did not increase RSA to evening values. However, lowering evening rectal or muscle temperatures to morning values by passive pre-cooling did decrease RSA to values normally observed in the morning. This highlights the different physiological mechanisms involved when cooling or warming the body core and muscles. Therefore, the diurnal variation in RSA could partly be attributed to diurnal changes in core and muscle temperatures. However, the causal link that has been proposed does not seem simple, but rather due to a multiplicity of components and mechanisms. it may be beneficial to pursue the contribution of the body clock to the diurnal variation in performance and look to use either chronobiotics such as bright light or exercise [32], to directly shift the body clock or dawn simulators to improve mood [33] – to ultimately increase morning gross muscular performance and aid athletes have to compete or undergo training in the morning.

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TABLE and FIGURES:

TABLE 1 Mean (±SD) values for temperatures, repeated sprint variables, subjective measures and blood variables measured in the five conditions. Statistical significance (P<0.05) is indicated in bold, and where 0.10>P>0.05 is indicated in italics. a - Different from the E condition (P<0.05); b – Different from the E_{MR} condition (P<0.05); c – Different from the E_{MM} condition (P<0.05); d – Different from the M_E condition (P<0.05).

TABLE 2 Correlations between temperatures (T_{rec} and T_m at 3 cm depth), performance for repeated sprint, RPE, effort and TC.

FIGURE 1 Schematic of the protocol for the 5 conditions - the morning (M, M_E 07:30 h) and evening (E, E_{MR}, E_{MM} 18:00 h) conditions. Rectal (T_{rec}) and muscle (T_m) temperatures, thermal comfort (TC) and perceived onset of mood (POMS) were measured after the subjects had reclined for 30 min at the start of the protocol and again after the warm-ups and prior to the RSA measures. * denotes start of 5 min of continuous T_{rec} baseline measurement; the average value of these 5-min was defined as resting T_{rec} and used in the subsequent analysis. Rating of effort (0-10 VAS), TC, HR and ratings of perceived exertion (RPE) were taken throughout the repeated sprint ability (RSA) protocol; **vertical black bars** indicate muscle temperature (T_m) taken at these points. ■ indicates times of blood collection.

FIGURE 2 Mean and 95% confidence intervals (corrected for between-subject variability) for rectal temperature and muscle temperature (at a depth of 3 cm) at rest (□) and post warm-up (■). a - Significant diurnal variation in temperature, where the resting morning value (07:30 h) is lower than the resting evening value (17:30 h; P<0.05). b - Temperature values significantly lower at rest than after the warm-up (P<0.05). c - Temperature values significantly higher at rest than after the cool-down (P<0.05).

FIGURE 3 Mean and 95% confidence intervals (corrected for between-subject variability) for distance covered, power (peak and average) and speed (peak and average) from sprint 1 to 10 for morning (□), evening (■), M_E (▲), E_{MR} (●) and E_{MM} (×) conditions. Dashed lines indicate averages and full lines indicate peak variables.