ABSTRACT

The aim of the present investigation was to compare responses to sustained exercise in the morning and evening in the heat (35°C) over a hilly prolonged simulated course. The thermoregulatory response examined was core temperature (Tc). In addition power output, and time were examined. Eight active males (25-40 years) were instructed to work as hard as possible over the entire exercise period, with variation of pedal frequency permitted at any time. Two prolonged sessions were performed at 08:00 and 17:00 h, and counterbalanced with at least 5 days recovery between tests. The examined variables showed no significant main effect for time of day. Mean power output in the evening was greater by 9 Watts (W) in comparison to the morning exercise. Furthermore, time increased by 2.8% in the evening compared to the morning. Future studies should include the examination of circadian rhythms and performance during undulating courses using each grat period.

KEY WORDS: Thermometric pill, environmental temperature, computer trainer, work output, athletic performance.
INTRODUCTION

During large-scale international athletic games, such as the Olympics, there is often a significant time difference between the location of the tournament and the countries where it is being broadcast. The question is, if the athletic committees change the time of the events (especially to the morning rather than the evening hours) in order to convenience these problems, is there a chance that athletic performances will be affected? A review by Waterhouse (21) supports this notion. From the review, it was concluded that endogenous circadian rhythms, such as body temperature, peak between approximately 16:00-20:00. During the night, when the body is at rest, these values decrease to a minimum between the hours 03:00-06:00. This diurnal variation influences athletic performance (21, 22).

Previously, many researchers have studied the difference in athletic performance at different times of the day (3, 4, 5, 15, 16, 18). Usually, in these studies, which are carried out under controlled conditions, cycling activity is used to simulate competitive performance (7).

Unique to this investigation is the fact that this externally valid performance test was carried out at two different times of day: 08:00 and 17:00 hours. The thermoregulatory response examined was Tc. In addition, power output and time were examined during a fluctuated specific course. These variables were examined during 3 laps of 9 km each. The course which was simulated is that of Fort William in Scotland, where the mountain bike World Championship was held in September 2007. The aim of this investigation is to assess whether performance varies between times of day when performing exercise on a simulated hilly course.

MATERIALS AND METHODS

SUBJECTS

Eight moderately active males who regularly cycle and were not acclimatised to heat attended the laboratory on three separate occasions. Ethical approval was gradient by the ethics committee of the Liverpool John Moores University. The characteristics of the subjects are presented in Table 1.

Prior to testing, a composite morningness questionnaire (20) was completed by all subjects with one subject being defined as an outright morning type (a lark) and the other seven defined as neither larks nor owls. On the first laboratory visit, maximum oxygen uptake (VO2 max) was measured utilising an incre-
mental cycle ergometer test to exhaustion. The other two visits were used as experimental testing sessions and consisted of cycling over the said distance of 27km (3 times 9 km) on a computer trainer (figure 1 and 2). Experimental testing was performed twice a day (08:00 and 17:00 hours), and administered in a counterbalanced fashion (5). Experimental testing took place in the months of June and July, during maximum daylight hours. Prior to testing, Tc was measured via a measuring device (Core temp, HQ inc. Florida, USA), which picked up transmissions from a gastrointestinal pill (Holnc Palmetto, FL 34221 USA) previously ingested by each subject ten hours before each test session (23). Subjects proceeded to enter an environmental chamber under a high temperature (35°C), and subsequently completed a five minute warm-up on their own bike at an intensity of 60% of their maximum work output (predetermined from their VO₂ max test). Immediately following the warm-up, subjects completed the 27 km experimental testing session.

### Table 1. Characteristics of the subjects (mean and sd).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Group (n = 8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>30.5 ± 6</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>76.7 ± 6.9</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>180.5 ± 3.3</td>
</tr>
<tr>
<td>Maximal oxygen uptake (ml/min/kg)</td>
<td>56.5 ± 5.2</td>
</tr>
<tr>
<td>Morningness questionnaire</td>
<td>29.4 ± 8.2</td>
</tr>
<tr>
<td>Maximum work output power</td>
<td>307.5 ± 46.5</td>
</tr>
</tbody>
</table>

![Figure 1: The testing profile as were used in laboratory visits 2-3 under a temperature of 35°C prior the simulation.](image)
Statistical Analysis

The data were analysed using the Statistical Package for the Social Sciences (SPSS) for windows version 14, using a paired t-test in the case of performance times, and a two-way analysis of variances with repeated measures (2 level, morning and evening exercise) × time (5 levels) for all physiological variables except for power output (time = 3 levels). When Mauchly’s assumption of sphericity was violated (p < 0.75), the Greenhouse-Geisser correction was reported, otherwise the Huynh-Feldt correction was applied. Graphical comparisons between means and Bonferroni pairwise comparisons were made where main effects were present. Statistical significance was accepted at p < 0.05.

RESULTS

Core Temperature:

There were no significant main effects for time of day (F(1,7) = 0.258, p = 0.627) indicating no diurnal effects occurred. The mean Tc in the morning was 37.81 ± 0.92 (°C) compared to 37.94 ± 1.14 (°C) in the evening.

There was a significant main effect for time (F(1.386, 9.703) = 10.701, p = 0.006). Tc increased as exercise progressed, irrespective of the time of day exercise was performed.

There was no significant interaction between the time of day exercise was performed and time during exercise (F(1.528, 10.693) = 0.859, p = 0.422). The
morning Tc was observed as less than the evening Tc. From rest until between laps one and two, a steeper rise in Tc was observed in the morning exercise resulting in higher mean Tc towards the latter stages of exercise.

Tc at the end of exercise in the morning was 38.74 ± 0.86 (°C) compared to 38.55 ± 2.01 (°C) in the evening (Figure 3).

**Figure 3:** Core temperature (°C) responses during rest, after warm-up, 1 lap, 2 lap and 3 lap cycling exercise in the morning (♦) and evening (●) under hot (35°C) conditions (n = 8, mean ± SD).

**Power Output**

Power output data were analysed using the results of six subjects, as data on two subjects were lost. There were no significant main effects for time of day (F(1,5) = 3.378, p = 0.125) indicating no diurnal effects occurred. A greater mean power output occurred in the evening 210.56 ± 55.51 (W) compared to 201.83 ± 58.09 (W) in the morning.

There was a significant main effect for time (F(1.039, 5.193) = 17.249, p = 0.008). Power output decreased, irrespective of the time of day exercise was performed.

There was no significant interaction between the time of day exercise was performed and time during exercise (F(1.102, 5.511) = 0.738, p = 0.440). The power output was less in the morning than in the evening from the first to the last lap; mean values were 209.17 ± 62 (W), 203 ± 61.03 (W), 193.33 ± 61.24 (W) in the morning and 216 ± 60.96 (W), 210.83 ± 58.67 (W), 204.33 ± 56.82 (W) in the evening for laps 1, 2 and 3 respectively. A more rapid decrease in power output was observed in the morning between the second and third laps in comparison to the evening (Figure 4).
Figure 4: Work output responses during 1 lap, 2 lap and 3 lap cycling exercise in the morning (♦) and evening (■) under hot (35°C) conditions (n = 6, mean ± SD).

**Time**

Exercise in the morning was completed in 4138.63 ± 264.19 sec compared to 4021.75 ± 243.69 sec in the evening, equating to a difference of 116.88 sec and representing approximately a 2.8% difference. There was no significant difference between conditions ($t(7) = 1.634, p = 0.146, p > 0.05$).

**DISCUSSION**

In the current study, the main findings during the times of testing indicated that $T_c$, power output and time showed no significant main effect for time of day. The power output and time in the evening time were greater by approximately 9 W and 2.8% respectively. This was the case even among athletes who showed a tendency towards being intermediate type persons, with a 29.4 ± 8.2 score, who woke at least 2 h before the morning test. Their performance was slightly better in the evening time.

The main finding for $T_c$ showed that there was no significant main effect for time of day. Also, in the current investigation, baseline (resting) $T_c$ was lower in the morning than in the evening inside the environmental temperature chamber, which was set at 35°C. This is a commonly found result (12, 16) and attests to the robustness of $T_c$ as a marker for circadian rhythms.

In the current study, the results indicate that the effect on $T_c$ during fluctuating prolonged exercise differed between the morning and evening in a
group of moderately active males. Thus, the increase in resting values of Tc during the prolonged exercise was more marked in the morning. This was particularly pronounced between laps 1 and 2, at which point a steeper rise in Tc was observed in the morning exercise, resulting in a higher mean Tc towards the latter stages of exercise. Tc at the end of the morning exercise was higher compared to the end of the evening exercise, with the same environmental conditions each time (35°C). This is in agreement with the results of the research of Aldemir (1), but differs from the results of Atkinson & Reilly (3), Reilly & Garrett (15). However, the latter two researchers concentrated on specific time on flat courses under a temperature of approximately 20°C. The present observations lend some support for the views that sustained exercise performance is not adversely affected by a morning starting time. The mean Tc in response to exercise maintained a time of day effect throughout the period of exercise.

In the current investigation, power output showed no significant main effect for time of day. A greater mean power output occurred in the evening at approximately 9W compared to the morning. These results have commonly been found in studies such as Atkinson & Reilly (3), Atkinson (2, 5). However, in these studies, power output had a significant effect for time of day with greater values in the evening compared to the morning. In addition, from these studies it could be concluded that the major finding was that self-chosen work rate exhibited circadian rhythmicity. Furthermore, they had greater performance in the evening over the first part of the test and this was compensated for by the improvement in power output in the morning over the second half of the test. This may be related to a diurnal variation in pacing strategies with prolonged bouts of cycling that seem to be related to the circadian variation observed in Tc (15). In the current study, power output was higher in the evening time during the start of exercise compared with the morning but both show a continuous decrease regardless of the time of day.

A greater performance was observed in the evening time (116.88 sec compared to the morning session). This difference represents approximately 2.8%. There was no significant difference between conditions, but these findings would be practically meaningful to competitive cyclists in real terms (6).

According to a review by Drust (7), a general parallelism exists between rhythms of physical performance and Tc. This parallelism is seen in many studies which have been carried out under normal conditions. A casual link between physical performance and Tc has often been assumed, as a rise in temperature promotes the activity of muscles and nerves, metabolism, and the cardiovascular and respiratory systems. Also, a study by Reilly & Garrett (15) has concluded that Tc is lower in the earlier part of the day, and this accounts for the observation that self chosen work rate can be better sustained at this time of day in exercise exceeding a 60 min duration (that is, when Tc is rising from a lower starting point). In the current study, a better perfor-
mance was observed in the evening time when the Tc had a higher starting point compared to the morning time. Also, the observation was made that the morning Tc was less than the evening Tc from rest until between laps 1 and 2, at which point a steeper rise in Tc was seen in the morning exercise. This resulted in higher mean Tc towards the latter stages of exercise. Aldemir (1) stated that during the early morning exercise the body clock causes the endogenous (clock-driven) component of Tc to be increased at this time, therefore subjects were in a heat gain mode, and the thermoregulatory mechanisms were directed more towards heat conservation than heat loss. As a result, «the heat load produced by the exercise induced a quicker increase of Tc and a less rapid dissipation of the heat load by dilation of the vascular beds of the limbs» (1). During the late afternoon, by contrast, a balance between the heat loss and heat gain modes was present since the endogenous component of Tc was near its peak as a result; heat-loss mechanisms were engaged more readily. An interaction between the circadian rhythm of Tc and changes in temperature produced by activity has been found in studies in mice and humans. Since the mechanisms for producing the circadian rhythm of Tc and protecting the body against a heat load are very similar in humans, there is an interaction between the two. As a result of this, some aspects of thermoregulation vary at different times of the 24 h clock (1).

In addition to this, a study by Reilly & Brooks (14) stated that the variations in Tc should be a mirror image of changes in skin temperature, which in turn reflect alterations in vasomotor control mechanisms. This raises interesting questions about the added heat load that can be tolerated at different times of day before exercise performance is limited and heat injury becomes a risk. Most guidelines operate either implicitly or explicitly on the basis of absolute values for stages of heat illness and heat injury. An implication of this is that the margin from resting baseline to the risk threshold would be greater in the morning than in the late afternoon by approximately 0.6°-0.7°C. This would be an additional reason for supporting morning rather than afternoon marathon race start times in hot climates, quite apart from the variations in environmental temperature that can be expected with time of day. Also, in the current investigation it was easier to see heat injury especially in the evening time when the Tc has a higher rest value compared to the morning in the environmental chamber set at (35°C). These points are supported by (Galloway & Maughan (10), Parkin (13) who stated that increases in body temperature induced by high ambient temperature consistently reduce the capacity to perform prolonged submaximal exercise.

Youngstedt & O'Connor (24) postulated that diurnal variation in performance may not be due to endogenous mechanisms but more likely to the preference of the athlete to train at certain times of the day. Atkinson (5) conducted a study using cyclist's and found that these subjects were relatively higher in morningness than eveningness. This means that they preferred to schedule
sleep-wake habits and activity at earlier than average times of the day. In this study, one of the participants was a morning type person and a higher performance was observed in the morning time. Another seven participants were intermediate persons and a higher performance in was observed in the evening time for all with the exception of one participant. The mean chronotype score in the participants was 29.4 ± 8.2, which indicates they are intermediate type persons, and may prefer to schedule sleep-wake habits and activity at average times of day. This intermediate subject dominance may explain why no significant main effects were found for time of day in performance.

In the current study, while the measurements were being taken, the power output data were lost for two participants; hence only six participants were represented for power output. Two participants exercised in a higher temperature in the evening and another participant exercised in a higher temperature in the morning with 40°C being the average temperature during the exercise, which may have confounded the results. Similar studies like Atkinson & Reilly (3), Atkinson (5) were used to represent current literature and make comparisons. The current literature concluded that there was a higher mean power output in the evening time compared to the morning time during 80min of submaximal exercise, although the work rate decreased sharply towards the end of the evening exercise. Another study lends support to this notion as better performance was exhibited at 17:00 compared to 07:30 h at approximately 20°C, even with a prolonged warm-up time of 25 min. In these two studies, the power output and performance were statistically significant. In the current study, the time and power output were not statistically significant. According to the current literature, it was expected that the same trend would emerge for power output. That is, higher power output in the evening than in the morning and a sharp decrease towards the end of the evening exercise. It is possible that in the current study, the fact that power output did not confirm this trend was due to a different design of the course being used, in contrast to the above studies. In the current study, an undulating course was employed which included climbing, downhill and flat bouts of cycling. In the above studies, the researchers used specific time flat courses only. It can be hypothesised that the subjects’ strategies differed for each different fluctuation during the course. It may be for this reason that work output power was higher in evening time during the start of exercise compared with the morning (as in the above studies) but both show a continuous decrease regardless of the time of day. Future studies should include examination of the diurnal variation for each gradient period for the overall distance of the course.

In summary, time of day showed no significant effect on the physiological variables observed in this study, thus indicating no diurnal effects. Mean power in the evening was greater by 9 watts in comparison to the morning and time increased by 2.8%. Future studies should include the examination of circadian rhythms and performance during undulating courses using each gradient period.
REFERENCES


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