Environmental Physiology
The Effects of Cool and Warm Temperature on
Selected Physiological Variables

INTRODUCTION

The importance of ambient temperature on exercise performance is well documented. It is suggested that a cool environment may be beneficial in maintaining thermally tolerable conditions in spite of intense exercise (Werner, 1993). Additionally, several studies have acknowledged that exercise in the heat can impair performance (Febbraio et al. 1994; Nielsen et al. 1984).

Several studies have examined the physiological responses to heat and cold during exercise in order to account for these variations. Heat was reported to markedly increase VO_2, heart rate and significantly elevate mean skin and core temperature (Galloway and Maughan, 1997). A higher ambient temperature is also seen to increase skin blood flow (Gonzalez-Alonso et al. 1999). This increased dependence of thermoregulation is seen to impair performance. Similarly, low ambient temperatures (0^oC) have been reported to induce a decline in performance. Heart rate is lower and oxygen consumption is higher and muscle glycogen utilisation is lower. It has also been reported that cold can reduce maximum oxygen uptake (Bergh and Ekblom, 1979). Recent studies have suggested that the optimal temperature for exercise performance is around 11^oC and that the relationship between exercise capacity and temperature follows an inverted U-relationship (Galloway and Maughan, 1997).

Therefore the aim of this investigation is to examine several physiological responses during a fixed intensity cycling bout under two contrasting environmental conditions. It is hypothesised that during the hot conditions there will be significant higher increases in heart rate, mean skin and core temperature, skin blood flow, lactate, VO_2, RER and RPE compared to the cold. Furthermore we postulated that in the heat there will be significant larger decreases in weight loss and plasma volume due to increased sweating.

METHODS

Subjects

The investigation was conducted on six healthy male subjects who had an average age of 22 $\pm$ 2yrs, weight 78kg, and height 175cm. The subjects were informed of the demands of the sessions and the risks and discomforts associated with the testing before providing their consent in writing to participate.

General Design

To identify the influence of temperature on physiological variables two studies were conducted. The first study was performed in cool conditions and the second in hot conditions. The tests were performed in an environmental chamber so that the temperature could be manipulated to suit. Throughout the test several techniques were adopted in order to measure changes in selected physiological variables. The intensity of the exercise was fixed for both tests (65% VO_2 max).

Experimental Design

The study required the subjects to perform two 30-minute exercise bouts on a cycle ergometer (model 814, E, Monark) in a hot environment (30 °C) and cool conditions (15°C) at a controlled relative humidity of 50% for both. The temperature on each of these occasions was controlled in an environmental chamber in which the subjects performed. All subjects cycled at a fixed power of 150 watts and a speed of 60 RPM, which corresponds to an exercise intensity of approximately 65% VO_2 max.

On the day before the test the subjects adopted the same diet and refrained from any exercise. To avoid any circadian variation the two tests were performed at the same time of day. In addition to this the two experimental testing sessions were separated by a week to eliminate any training or fatiguing effects.

Measurements

Several baseline measurements were taken before the exercise bouts. This required the subjects to rest for at least 15 minutes, were after heart rate, blood lactate, mean skin and core temperature, and skin blood flow were taken. Continued measurement of heart rate, core temperature, skin blood flow, mean skin temperature, and RPE was conducted throughout the test with measurements being taken every 5 minutes. Blood lactate, haemoglobin, haematocrit, VO_2, and RER were also recorded after 15 mins and at the end of the bout. Nude body mass was recorded before and after to determine weight loss during exercise due to sweating.

Blood Sampling and Analysis: Blood samples were obtained using a softclix on the fingertips of each subject at rest and every 15 mins until the end of the exercise. For the resting sample the subject was required to sit for up to 15 minutes before blood was taken. Blood was taken so that lactate, haematocrit, and haemoglobin could be analysed. Lactate was measure in the Analox GM7 Pro Analyser and Haemoglobin was analysed using the Haemocue. The blood was also spun using a microcentrifuge so that haematocrit could be determined (Hawskey Analyser, England). Haematocrit and haemoglobin values were used to calculate plasma volume change (Dill and Costill, 1974).

Skin Blood flow: Blood flow was determined throughout the test using a Perimed Laser Doppler flowmeter. The probe was taken on the dorsal side of the forearm and the values were recorded at rest and every 5 mins until the end of exercise.

Core and Skin Temperature: Core temperature was measured using a First Temperature Genius placed in the ear. Readings were taken at rest and every five minutes during exercise. Skin temperature was determined by taking an average of three skin cites around the body. Skin thermistors were placed on the calf, forearm, and below the sternum notch and attached to a Grant Data Logger to collect data at rest and every five minutes. Mean skin temperature was calculated using: (0.5 x Sternum) + (0.14 x Forearm) + (0.3 x Calf).

Heart Rate and RPE: Heart rate was measured during each trail at rest and every five minutes during the test until the end of the exercise. The data was determined using a heart rate monitor and wrist watch (Polar Sports Tester). The subjects' subjective feelings were recorded at five-minute intervals during exercise using a Rating of Perceived Exertion scale determined by Borg.

Weight Loss: Nude body mass was determined used counter-balanced weighing scales before and after each exercise trial. After the exercise bout the subjects' were made to wipe of any excess sweat on the body in order to produce an accurate reading.

VO_2 and Respiratory Exchange Ratio: Respiratory exchange data were collected after 15 min and the end of the exercise using a Douglas Bag. Expired air was collected and analysed for concentrations of O_2 and CO_2. Outputs from these gas analysers were interfaced with a computer that calculated VO_2 and RER.

Statistical analysis: The data from both the cool and warm experiments were compared using repeated measures analysis of variance (ANOVA). For weight loss a paired sample t-test was performed. A significance level was set at $P < 0.05$. Results of the statistical analysis can be found in appendix 1.

RESULTS

Cardiovascular Responses. At rest heart rate was similar during both cool and hot conditions (68.2 $\pm$ 6.97 and 71.2 $\pm$ 9.71 respectively). When exercise starts it is apparent that heart rate increases with time in both conditions ($p = 0.000$, $P < 0.05$), which can be seen in figure 1. Further analysis of figure 1 shows clearly that heart rate values are higher in the hot conditions and this difference can be considered significant ($p = 0.007$, $P < 0.05$). At the end of exercise heart rate in the heat was 161.5 $\pm$ 7.79 compared to 142.33 $\pm$ 4.52 in the cold. It is also apparent that there is a significant interaction between the two factors (time and temperature) ($P<0.05$).

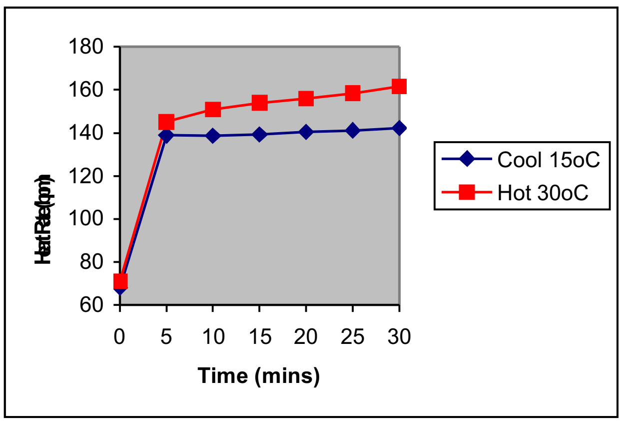

Figure 1. Heart Rate values during exercise in the heat and cold.

On analysis of the VO_2 data (Appendix 2) there is a limited difference between 15 and 30 minutes and between the two testing conditions. Furthermore the differences are considered not to be significant ($p = 0.384$, $P > 0.05$; $p = 0.665$, $p> 0.05$). Statistical analysis also shows no significant interaction between the trial and time. Examination of Figure 2 below shows that contradicting responses are present in the hot and cold when considering respiratory exchange ratio. In the cool environment the RER value decreases from 15 to 30 minutes whereas in the hot environment there was an increase from 15 to 30 minutes ($p = 0.000$, $P < 0.05$). However the differences in RER over time are not significant ($p = 0.164$, $P > 0.05$). The results also indicate significant interaction between time and temperature ($P < 0.05$).

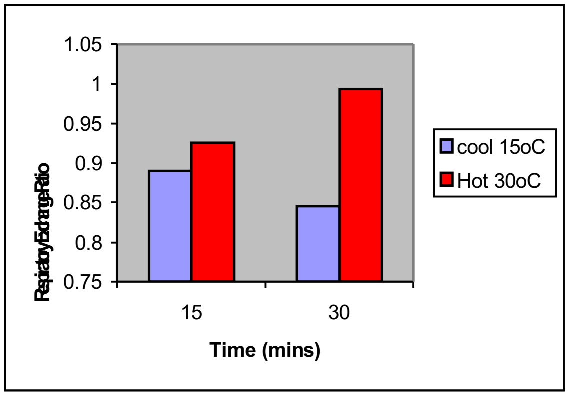

Figure 2. RER values during exercise in the heat and cold.

Mean Skin and Core Temperature. From figure 3 it is clear that the temperature of the exercising environment has a large effect on both skin and core temperature ($p < 0.05$).

Mean skin temperature is significantly higher in the hot than in the cold environment shown by the two distinct lines (figure 3). The mean skin temperature in the hot was around 33-34 ^{o}C compared to 29-30 ^{o}C in the cold. Core temperature increases in both exercise conditions from a similar resting temperature. However it can be seen from figure 3 that the increase is higher in the hot compared to the cold. Statistical analysis highlights that this higher increase in the hot is significant ($p = 0.024$, $P < 0.05$). It is also evident that in both variables the increase in the values throughout the testing is significant ($P < 0.05$). Considering core temperature, it is evident that there is significant interaction between the two factors ($P < 0.05$), which is not evident for mean skin temperature ($P > 0.05$).

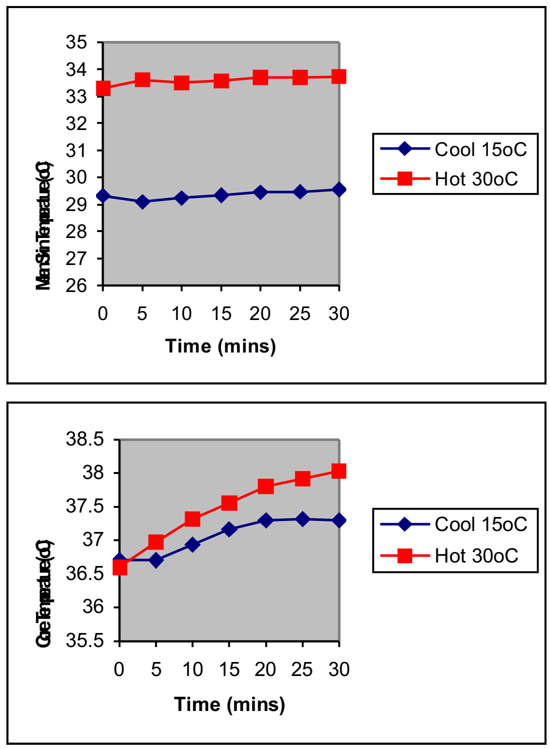

Figure 3. Mean skin and core temperature during exercise in the heat and cold

Blood Lactate: Resting concentrations for lactate were similar in cold and hot conditions (1.27 ± 0.61 and 1.17 ± 0.5 respectively). Throughout the test in both conditions the lactate concentrations increased significantly ($p = 0.000$, $P < 0.05$). Figure 4 shows that this increase is significantly higher in the hot conditions when compared to the cold ($p = 0.000$, $P < 0.05$). In the hot, concentrations reached 4.4 mmol whereas in the cool the levels only reached 2.04 mmol. Significant interaction between temperature and time is also evident for blood lactate ($P < 0.05$).

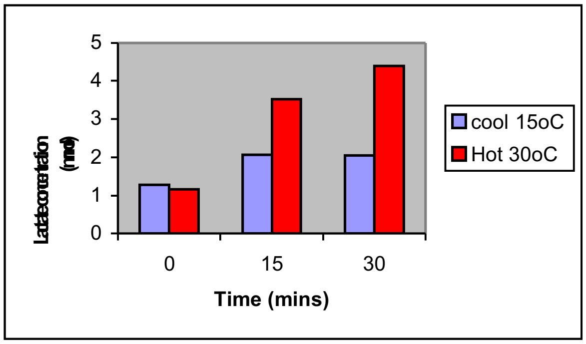

Figure 4. Lactate concentration during exercise in the hot and cold.

Skin Blood Flow. During exercise skin blood flow increased over time in both conditions (p = 0.000, P < 0.05). Initially in the cool conditions concentration increased but then hits a plateau at around 5 minutes, whereas in the hot condition skin blood flow carried on increasing with no plateau occurring within the exercise duration (Figure 5). The distinction between the two environmental conditions can be seen clearly and furthermore this difference is statistically significant (p = 0.001, P < 0.05). The results also indicate significant interaction between time and temperature (P < 0.05).

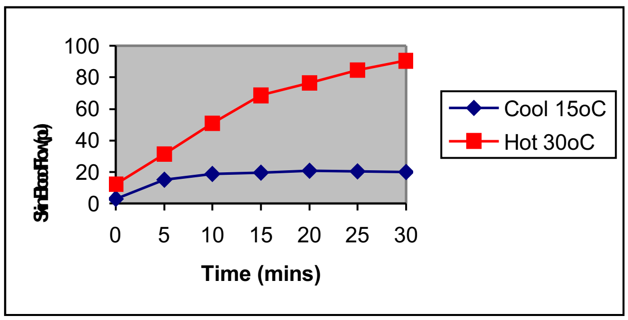

Figure 5. Skin blood flow during exercise in hot and cold conditions

Plasma Volume Responses: The change in plasma volume was significantly different between trials (p = 0.015, P < 0.05). Plasma volume decreased in both environmental conditions between rest and the 30-minute sample time (p = 0.000, P < 0.05). However the decrease in the hot conditions was larger in the hot compared to the cold shown quite clearly in figure 6. The end percentage decrease in plasma volume was 9.75% in the hot compared to 5.45% in the cold. The statistical analysis shows that there is no significant interaction between the two factors (P > 0.05).

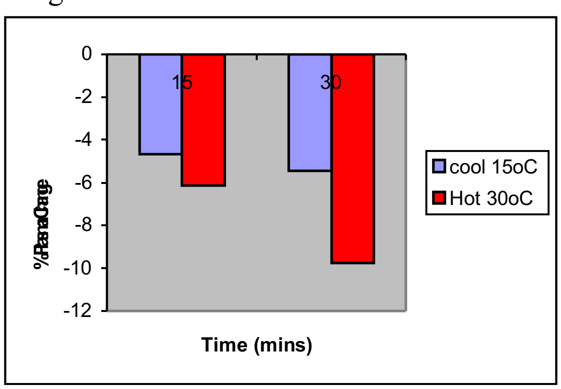

Figure 6. Plasma volume responses during exercise in the hot and cold.

Weight loss: Analysis of the data (Appendix 2) shows that weight loss was higher in the hot condition compared to the cold environment. The weight loss of the subjects in the hot was double that of those in the cold (0.5 kg and 1kg respectively). The result of the paired sample t-test (Appendix 1) shows that the difference over trials is significant ($p = 0.000$, $P < 0.05$).

RPE. After 10 minutes of exercise the RPE scores were similar in both experimental conditions. Thereafter, RPE was higher in the hot environment compared to the cold. However, it was found that these higher values were not significant ($p = 0.233$, $P < 0.05$). In both trials RPE increased over time (Cold, 10.5 $\pm$ 0.96 to 12 $\pm$ 0.82; Hot, 10.3 $\pm$ 0.75 to 13.3 $\pm$ 0.75) and statistical analysis showed that these increases were significant ($p = 0.000$, $P < 0.05$). Significant interaction was found for the two factors on analysis of RPE.

DISCUSSION

The main aim of this investigation was to examine selected physiological variables and their response to a bout of cycling exercise in hot (30^oC) and cold (15^oC) conditions.

Heart Rate. Heart rate was markedly increased during the exercise bout in the hot conditions compared to the cold. Gonzalez-Alonso et al. (1999) stated that endurance athletes experience a lower heart rate (10 bpm) whilst performing in the cold rather than the hot at the same exercise intensities. It is suggested that the increased heart rate during exercise in the heat may be down to reductions in stroke volume. During exercise in the heat, stroke volume is decreased because more blood is sent to the periphery (increased skin blood flow) to enable increased heat loss but as a result there is less venous return (Nielsen et al. 1984). Therefore in order to maintain cardiac output, heart rate is increased to balance the equation. This increase in heart rate experienced in this investigation is supported by several other studies (Galloway and Maughan, 1997; Gonzalez-Alonso et al. 1999).

Mean Skin and Core Temperature. The main finding in both these variables was that exercise induced an increase in temperature in both conditions. This is because strenuous exercise in any environmental condition produces heat, some of which is stored raising body core temperature by a few degrees (Gleeson, 1998). However, mean skin and core temperature increased more in the hot environment and it is suggested that during exercise in the heat, the increase in environmental temperature impairs the dissipation of heat, which leads to the development of hyperthermia (Hargreaves and Febbraio, 1998). It is also suggested that during exercise in the heat athletes lose 1-2 l/h of fluid due to thermoregulatory sweating (Gonzalez-Alonso, 1998). This causes dehydration, which is accompanied by higher and faster increases in core temperature because the capacity to sweat is impaired (Fortney et al. 1981). The higher mean skin temperature can be explained by the increased skin blood flow associated with exercising in the heat.

Lactate and Skin Blood Flow. As expected lactate concentration increased throughout the performance of each exercise bout. However the main finding in this area was that the increase in concentration was significantly higher in the hot (30°C) environment compared to the cooler (15°C) environment. This finding is to be expected considering other reports on metabolic responses to thermal stress. Fink et al. (1975) looked at the influence of environmental heat stress on muscle metabolism during three 15-minute bouts of cycle exercise. They reported a higher measured concentration of blood lactate when the exercise was performed in the heat compared to the cold environment. Furthermore, the increase was reported to almost double, which supports the data generated in this study. However, our findings also contradict results from a recent study conducted by Ball et al. (1999). They examined thermal stress and performance of repeated cycle exercise. The results generated showed that the concentration of blood lactate after exercise in the heat was similar to that under the normal condition. The reason for these contradictory conclusions may be because the intensity of the exercise was different in this and our investigation. The later study looked at repeated sprint exercise whereas in this investigation we examined responses during sub-maximal exercise.

This increased lactate production in the heat may be caused by an increase in blood flow to the skin. The results of this study show that skin blood flow was dramatically higher in the hot conditions compared to the cold. At the end of the exercise in the hot, skin blood flow was almost 4.5 times that in the cold and this may be a reason for the higher lactate concentrations. The increase skin blood flow is because the body needs to lose heat in order to regulate the body's temperature by sweat evaporation. Sweat reduces skin temperature resulting in a wider heat gradient. Therefore less blood is sent to the gut and visceral and is redistributed to the skin so that heat can be lost easier (Wilmore and Costill, 1994). However more blood being pumped to the skin results in less blood flow to the working muscles and consequently less O_2 deliverance to the muscles. This means that the body is more dependent on anaerobic processes and therefore continued work produces an increased amount of lactic acid. This may also explain why the subjects perceive the exercise to be harder that in the cold highlighted by the higher RPE values found in the results.

Respiratory Exchange Ratio. The main finding in this area was an increase in RER in the heat and a reduction in RER in the cold. It is suggested that during exercise in the heat less O_2 is delivered to the working muscles and therefore fuel utilisation is effected. The exercise depends more on anaerobic processes and therefore there is a greater breakdown of carbohydrates hence the higher RER value (Hargreaves, 1995). Kay and Marino (2000) suggested that further stress on glycogen stores in the heat was due to elevated catecholamines stimulating glycogenolysis in inactive muscles. It is also suggested that during cooler conditions there is a greater metabolic efficiency and this may explain the decrease in RER in the cold trial.

Plasma Volume Responses. Plasma volume decreased in both environmental conditions with a greater decrease noted in the hotter temperature. These results follow the findings of a study conducted by Harrison et al. (1975) who analysed haematocrit, haemoglobin, and plasma protein concentrations. They found that changes in the measures were consistent with a significant reduction in plasma volume during exercise in the heat. This increased loss in the heat is due to increase amounts of sweating and fluid shifts.

VO_2. The literature in the area of VO_2 is inconsistent and several studies have found conflicting results. The results from this investigation seem to show that VO_2 was lower in the cold conditions compared to the hot. The results are supported by Fink et al. (1975) who observed a higher VO_2 in the heat (41°C) compared to a cold environment (9°C). However, Galloway and Maughan (1997) found that VO_2 was lower in the hot (31°C) trial compared to cooler tests and suggested that these variances in studies may be related to factors such as intensity, protocol that influence oxygen cost of exercise.

Weight Loss. The data generated in this study show that weight loss occurred under both conditions. This weight loss was down to water loss via sweating and therefore because the subjects sweated more in the hotter environment they consequently had a greater weight loss than when the test was performed in the cold. This variable shows a close correlation to plasma volume responses described above.

CONCLUSION

The results generated in the above study and current literature suggest that performance is favoured in the cold conditions. It has been highlighted that an increased core temperature is a major limiting factor during exercise (Gonzalez-Alonso et al. 1999). Furthermore it is evident that the increased stress placed upon the body in order to regulate the body's temperature impairs mechanisms needed for optimal performance. Skin blood flow was increased dramatically, which impaired O_2 delivery to the working muscles and consequently increased lactate concentration. However no strong conclusions can be made on temperatures effect on performance because a major limitation of this study was that no performance criteria were performed. Therefore if the investigation was to be repeated then it must be ensured that a time to exhaustion and/or distance covered measurement be taken so that this area can be concluded properly.

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