`Research article`

EFFECT OF 30°C HEAT ON THE ANAEROBIC CAPACITY OF HEAT ACCLIMATISED ATHLETES

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ABSTRACT

The main finding of this study was that for heat acclimatised athletes, there was no significant difference (p=0.58) in anaerobic capacity for temperate (21.8 ± 0.5 °C; 52 ± 5 % relative humidity) compared with warm conditions (29.6 ± 0.5 °C; 51 ± 9 % relative humidity). Anaerobic capacity was estimated using the maximal accumulated oxygen deficit (MAOD) during constant intensity cycling at 120% peak rate of O_2 consumption until exhaustion. This yielded mean MAOD values of 3.3 ± 0.9 and 3.5 ± 1.1 L for temperate and warm conditions, respectively. Peak post-exercise lactate values of 14.7 ± 3.8 and 14.4 ± 4.5 mmol· L^{-1} for temperate and warm conditions respectively, were also not significantly different (p=0.72). Time to exhaustion (TTE) was similarly unchanged (p=0.56), being 175 ± 19 and 170 ± 18 s for temperate and warm conditions, respectively. These results suggest that the MAOD remains a valid test throughout environmental temperatures for the range of 20-30 °C when used with heat acclimatised athletes.

KEY WORDS: Maximal accumulated oxygen deficit, anaerobic metabolism, environmental temperature, maximal exercise

INTRODUCTION

Coaches are often interested in quantifying the potential of athletes for high intensity, short duration performance. Anaerobic capacity expresses the total amount of energy that may be derived during maximal exercise from non-aerobic sources before exhaustion prevents the athlete from continuing. Traditionally, the Wingate test has been used but as it fails to factor out the considerable aerobic contribution, mean power and anaerobic capacity are not analogous and the originators of the test discourage the comparison (Inbar et al., 1996). The maximal accumulated oxygen deficit (MAOD) test represents an advance on the Wingate test because it is able to isolate and quantify the anaerobic contribution to performance of this nature.

Calculation of the MAOD is based on extrapolating an athlete's power output to oxygen consumption relationship to determine the theoretical oxygen cost (oxygen demand) during the test and then to subtract the actual oxygen consumption. A recent presentation of the protocols, normal values and rationale for the test may be found in Finn et al. (2000).

While the effects of warm and hot conditions on aerobic exercise have been extensively investigated, it was the intention of this study to address the paucity of research on the effects of warm conditions on anaerobic performance and metabolism. The Wingate test has previously been used to demonstrate that anaerobic performance is not affected by environmental temperature by comparing effects at 22-23 °C with 30 °C and 38-39

°C (Dotan and Bar-Or, 1980). Given the aforementioned limitation of the Wingate test, we considered it necessary to investigate the effects of heat on anaerobic capacity using a more valid test. Although an early study (Claremont, 1969) found no difference in estimated oxygen deficits with an elevation of 1°C in rectal temperature, to our knowledge, this is the first study to investigate the effect of environmental temperature on the MAOD.

The increase in skin blood flow at the expense of exercising muscle perfusion during warm and hot conditions may result in a greater reliance on anaerobic metabolism. The MAOD quantifies the limited amount of energy that is available from anaerobic sources for an individual before exhaustion occurs, and as such is considered a finite entity. For example, a male endurance athlete may have a MAOD as low as 40 ml· kg^{-1} and an elite sprint athlete as high as 100 ml· kg^{-1} (Finn et al., 2000). The magnitude of the MAOD should not be affected by variables such as changes in environmental temperature. However, by inducing a greater reliance on anaerobic metabolism, environmental temperature may be a factor that influences the time taken to exhaust the anaerobic capacity. The purpose of this study was to test the hypothesis that during exercise in the heat the magnitude of the MAOD for heat acclimatised athletes should remain unchanged, although due to the greater reliance on anaerobic metabolism reported for exercise in elevated ambient temperatures (Dimri et al., 1980; Young, 1990; Febbraio et al., 1994), it may be exhausted sooner.

METHODS

Subjects

Five male and one female heat acclimatised subjects (25 ± 7 yr; 71.8 ± 4.4 kg; peak rate of O_2 consumption 56.8 ± 6.4 ml· kg^{-1}· min^{-1}) were recruited from Darwin triathlon and cycling clubs. Subjects were acclimatised on the basis of cycle training 10-17 hours per week outdoors in warm to hot conditions for a minimum of two years. Informed consent was provided before undertaking any of the tests required in this study. The experimental procedures were approved by the Human Ethics Committee, Northern Territory University (reference number H99041), and conformed to the principals set out in the current National Health and Medical Research Council regulations.

Design

The experimental treatments consisted of exercise in temperate (21.8 ± 0.5 °C; 52 ± 5 % humidity) and warm temperatures typical of the local environment (29.6 ± 0.5 °C; 51 ± 9 % humidity). Anaerobic capacity tests in these conditions were undertaken in random order on consecutive days. A series of preliminary tests to determine each subject's cycling economy and peak rate of O_2 consumption were also conducted in temperate and warm conditions.

Procedures

The MAOD test procedures were adapted from those of Medbø and Tabata (1989) and were conducted using an electromagnetically braked cycle ergometer (Lode BV, Groningen, The Netherlands) with O_2 consumption measured using a Medgraphics CPX/D gas exchange system (Medical Graphics Corporation, St. Paul, MN, USA). The duration of each stage in the cycling economy test was 5 min and the exercise intensity at each stage was 25W greater than the former. The six workloads spanned 75-200 and 100-225W for female and male subjects, respectively. On another day, a continuous incremental protocol was used to determine the peak rate of O_2 consumption of each subject. Regressions of O_2 consumption on power output obtained from the cycling economy tests were extrapolated to predict the oxygen requirements and workload at 120% peak rate of O_2 consumption. This workload has high test-retest reproducibility for constant intensity MAOD tests (Weber and Schneider, 2001). The anaerobic capacity test warm-up was for 10 min and consisted of the following: 3 min at 100W, 15 sec at 400W, 1 min at 100W, 15 sec at 400W, 3 min at 100W, 1.5 min rest while capillary blood sample taken, 1 min at 100W. The anaerobic capacity test comprised constant intensity cycling at 120% peak rate of O_2 consumption until exhaustion, at a self-selected cadence between 90-110 revs· min^{-1}. A given subject adhered to the same pedal cadence throughout the 2-3 min ride until exhaustion. Exhaustion was defined as a decrease in pedal cadence to below 60 revs.min^{-1} and occurred within a few seconds of the cadence dropping below the self-selected cadence. The MAOD was calculated from the difference between 120% peak rate of O_2 consumption and the actual oxygen consumption over the duration of the test, using the results from the tests performed under the same conditions.

In the anaerobic capacity tests, core (T_{core}) and skin (T_{skin}) temperatures were monitored using a rectal probe and skin thermistors (YSI, Yellow Springs, OH, USA), respectively. Mean skin temperatures were calculated from a weighted mean of chest (T_{st}, manubrium), forearm (T_{fa}, mid anterior surface) and calf (T_c, mid posterior surface) sites. The weighting was based on the relative proportion of each region to the body surface area in accordance with Ramanathan (1964):

$$T_{skin} = 0.5\, T_{st} + (0.14 \times T_{fa}) + (0.36 \times T_c)$$

Electronic scales (A & D Mercury, Pty. Ltd., Adelaide, Australia) were used to measure changes in bodyweight and fluid intake. Sweat loss was estimated from a comparison of these values. Heart rate was recorded every 5 s with a heart rate monitor (Polar Electro Oy, Kempele, Finland). Pre and 1, 3, 5 and 7 min post exercise capillary blood samples were taken from a hyperaemised ear lobe and a lactate analyser (YSI, Yellow Springs, OH, USA) was used to determine the changes in concentrations of lactic acid. Blood pH was measured and HCO_3^- calculated using a Ciba-Corning 865 blood gas analyser (Chiron Healthcare Pty Ltd, Scoresby, Victoria, Australia).

Data analysis

Comparisons between the experimental treatments and between various points in time were made with repeated measures ANOVA. Tukey post-hoc comparisons were used in the event of statistically significant differences. Student's paired two-sample t-tests were used for comparisons of means for the MAOD, TTE, and sweat loss between experimental treatments. The accepted alpha level was $p \leq .05$.

RESULTS

There was no significant difference in MAOD between the two experimental conditions. Mean values were 3.3 ± 0.9 and 3.5 ± 1.1 L (p = .58) for temperate and warm conditions, respectively. Time to exhaustion (TTE) was also unchanged, being 175 ± 19 and 170 ± 18 seconds (p = .56) for temperate and warm conditions, respectively.

Post warm up T_{skin} averaged 3.0 °C higher in the warm condition. It remained relatively constant during the anaerobic capacity test and increased by the same amount for temperate and warm conditions during the first six minutes of recovery. T_{core} prior to the warm up was 37.4 ± 0.2 and 37.3 ± 0.2 °C (p = .82) for temperate and warm conditions, respectively. Post warm up T_{core} was 37.5 ± 0.2 and 37.5 ± 0.3 (p = 1.00) for temperate and warm conditions, respectively. It continued to rise throughout the test by a statistically significant (p < .01) amount that was of the same order for both temperate and warm conditions. Post exercise core

temperature peaked at 38.0 ± 0.2 and 38.0 ± 0.3 °C (p = .71) for temperate and warm conditions, respectively.

There was a significant difference between the 320 ± 112 and 416 ± 131 g of sweat (accounting for fluid intake) that was lost in the temperate and warm conditions, respectively. However, this was not of any physiological significance because it only represented .5 ± .2 and .6 ± .2 % of the subject's body mass for temperate and warm conditions, respectively. Fluid intake was 100 and 136 ml for temperate and warm conditions, respectively, resulting in only minimal changes in body weight throughout the tests.

There were no significant differences between temperate and warm conditions at any time during the anaerobic capacity test or for pH and HCO_3^- concentration, or for peak lactic acid concentration (Table 1). Peak heart rates were 180 ± 6 and 180 ± 9 b· min^{-1} for temperate and warm conditions, respectively.

DISCUSSION

The principal findings of this study were that for heat acclimatised athletes, there were no significant differences in anaerobic capacity or in the time taken to exhaust the anaerobic capacity in a constant load test for temperate compared with warm conditions. The MAOD is a quantity and not a rate. Since both the stores of creatine phosphate and the extent to which lactate can accumulate are limited, then anaerobic capacity is finite and a separate entity from the aerobic energy system (Medbø et al., 1988). This study's comparison between temperature and warm conditions supports this concept. The concept of a finite entity independent of aerobic influence has also been supported with no change in the magnitude of the MAOD in the hypoxic condition (Linnarsson et al., 1974), in which the anaerobic contribution to performance is also isolated.

The markers selected in this study (Table 1) were unable to demonstrate an increased reliance on anaerobic metabolism in warm conditions. Blood lactate concentration reflects the balance between production and removal. Possibly elevated muscle

Table 1. Markers of anaerobic metabolism during the MAOD test. Data are means (standard deviation)

	Thermoneutral		Hot	
	pre	post	pre	post
pH	7.42 (.02)	7.17 (.04)	7.43 (.02)	7.18 (.04)
$[HCO_3^-]$*	24.5 (.67)	13.8 (1.01)	24.4 (1.18)	14.1 (1.13)
Peak [La]*		14.7 (3.8)		14.4 (4.5)

* values are expressesed in mmol· L^{-1}

temperatures during exercise in warm conditions may enhance lactate utilisation in heat acclimatised athletes and mask increased lactate production. Alternately, it is likely there was no increased reliance on anaerobic metabolism in heat acclimatised athletes in exercise of this nature.

According to our hypothesis, the expected performance decrement in warm conditions for a constant intensity MAOD test was an inability to maintain the supramaximal power output. Although the MAOD would be of the same magnitude, it would be more rapidly expended and this would be reflected in a decreased TTE. If there was an increased reliance on anaerobic metabolism it may result in an earlier onset of fatigue. The lack of evidence in this study to support an increased reliance on anaerobic metabolism was consistent with our heat acclimatised athletes maintaining their TTE in the warm environment.

Alternately, it is more likely that performance during exercise in the heat is substrate independent and depends on core temperature (Febbraio 2000). Performance decrement in a 40 °C environment has been associated with elevated muscle IMP concentrations at fatigue, despite adequate glycogen stores (Febbraio 2000) and elevated plasma ammonia but not lactate was reported with a 39.2 ± 1 °C core temperature (Marino et al. 2001). Heat acclimatised subjects may have more effective cooling mechanisms involving an earlier onset of sweating (Haymes and Wells 1986) and a change in the distribution of sweat such that a greater cooling effect is achieved for less fluid loss (Armstrong and Maresh 1991), thus maintaining core temperature and exercise performance. The present study's moderate ambient temperature of 29.6 ± 0.5 °C and the heat acclimatised athlete's ability to limit core temperatures to 38.0 ± 0.3 ° C with no significant difference between temperate and warm conditions, contributed to keeping athletes below the limits at which a reduced TTE may occur. However, we acknowledge the slow response time of rectal temperature and concede that core temperature measured in the esophageus may be greater, although it is unlikely the short test duration permits sufficient heat storage for athletes to reach a limiting core temperature.

CONCLUSION

The hypothesis that the magnitude of the MAOD should remain unchanged while exercising at 30 °C was supported by this investigation, but that it should be exhausted sooner was not. TTE was not reduced in the warm condition and there was no evidence of increased reliance on anaerobic

metabolism. The MAOD test appears unaffected by test conditions varying from 20 - 30 °C for heat acclimatised athletes.

ACKNOWLEDGMENT

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