

## THE METABOLIC AND THERMOREGULATORY RESPONSES TO PROLONGED WALKING EXERCISE IN COLD-EXPOSED MAN

Andrew Weller<sup>A</sup>, Claire Millard<sup>B</sup>, Mike Stroud<sup>B</sup>, Paul Greenhaff<sup>A</sup>, and Ian Macdonald<sup>A</sup>

A

Department of Physiology and Pharmacology  
University of Nottingham Medical School  
Queens Medical Centre  
Nottingham NG7 2UH  
UK

B

Army Personnel Research Establishment  
Ministry of Defence  
Famborough  
Hampshire GU14 6TD  
UK

### INTRODUCTION

In comparison to exercise in cold water, the development of hypothermia during exercise in cold air is relatively unlikely. However, Pugh (1) described incidents of accidental hypothermia in hill walkers and climbers, and noted that most cases occurred at temperatures near freezing point and in the presence of wind and rain. Pugh (1) also identified fatigue as a factor influencing the onset of hypothermia. Simulating a cold/wet/windy environment in the laboratory (+5°C dry bulb ambient temperature [ $T_{Amb}$ ] and a 4.2 m·s<sup>-1</sup> air current), Pugh (2) produced a cold stress that induced a 1°C decrease in rectal temperature ( $T_{re}$ ) and a 50% increase in oxygen consumption ( $VO_2$ ) during low intensity cycle exercise (67 watts or ~30% maximum oxygen consumption [ $VO_{2max}$ ]) compared with a cold/dry/no wind control condition. These differences were attenuated at 100 watts and abolished at 150 watts (~50-60%  $VO_{2max}$ ). Although only based on three subjects, these findings had important implications for the conduct of recreational and job related activities in cold environments. More recently, Hampton and Knibbs (3) extended Pugh's experiments to a larger sample size and observed a fall in  $T_{re}$  but no increase in heat production during cycle exercise at 55%  $VO_{2max}$  in a cold/wet/windy environment compared with a cold/dry/windy control condition. The aim of the present investigation was to establish a suitable laboratory model to investigate the physiological responses to prolonged walking exercise during cold exposure in man. This mode of exercise was deemed the most applicable to the study of human metabolism during adverse environmental conditions and avoided the problem of exacerbated leg muscle cooling observed by Hampton and Knibbs (3) in cycle exercise. Blood samples were collected along with thermoregulatory and metabolic measures, as little information is available regarding fuel utilisation and hormonal status under conditions of prolonged exercise and body cooling.

### METHOD

8 healthy men attempted a 6 hr intermittent (15 min rest, 45 min exercise) exercise protocol on two occasions in a climatic chamber against a 5 m·s<sup>-1</sup> air current. For the first 2 hr they walked on an inclined (10%) treadmill at 6 km·h<sup>-1</sup> (HIGH), after which they walked on the level at 5 km·h<sup>-1</sup> (LOW). In one condition,  $T_{Amb}$  was +6°C and clothing was periodically wetted with cold water (C), whereas in the other  $T_{Amb}$  was +15°C and clothing was not wetted (N). In C and N the subjects wore a cotton shirt and combat suit, with woollen socks and leather boots. In C, gloves and a balaclava were also worn. The subjects consumed a light, predominantly carbohydrate breakfast approximately 3 hr prior to each experiment. Mean skin temperature ( $T_{sk}$ : Ramanathan, 1964),  $T_{re}$ , and heart rate (HR) were recorded every 5 min. Expired air samples were collected 15 and 35 min into each exercise period, and venous blood samples were obtained from an arm via an indwelling cannula before entering the chamber and during the last 5 min of each exercise period. To ascertain the environmental influence on measured parameters, the HIGH and LOW data were analysed using two way analysis of variance for repeated measures (ANOVA factors were environment and time). Pearson product-moment correlations were calculated to determine relationships between variables. All data are reported as means±SE.

### RESULTS

The physical characteristics of the subjects were: age, 26±2 yr; weight, 76.1±2.2 kg; height, 1.75±0.02 m; surface area, 1.92±0.03 m<sup>2</sup>; body fat (BF), 16.0±1.9 %; and  $VO_{2max}$ , 53.6±1.6 ml·kg<sup>-1</sup>·min<sup>-1</sup>. HIGH and LOW equated to relative exercise intensities of 63.7±1.4 and 30.0±1.1 %  $VO_{2max}$  respectively during N. Three of the subjects were unable to complete C, consequently only data up to the end of the first hr of LOW (LOW 1) were included in the ANOVA. Baseline  $T_{re}$  values were similar ( $p>0.05$ : N; 36.86±0.09 vs C; 37.03±0.11°C), and the responses to the rest/work periods ( $\Delta T_{re}$  °C) at the end of each hour of HIGH (HIGH 1 & 2) and LOW 1 are tabulated below along with  $VO_2$  (ml·kg<sup>-1</sup>·min<sup>-1</sup>).

CONDITION	HIGH 1		HIGH 2		LOW 1	
	$\Delta T_{re}$	VO <sub>2</sub>	$\Delta T_{re}$	VO <sub>2</sub>	$\Delta T_{re}$	VO <sub>2</sub>
N	+1.34 ±0.07	33.4 ±0.7	+1.51 ±0.09	34.5 ±0.9	+0.86 ±0.05	15.9 ±0.4
C	+1.16 ±0.07 *	33.4 ±1.5	+1.11 ±0.11 **	33.6 ±1.9	+0.10 ±0.15 **	19.2 ±1.1 *

Between-treatment difference \* (p<0.05) \*\* (p<0.01)

The  $T_{re}$  response was variable in **C**, with a significant correlation ( $r=0.809$ ;  $p<0.01$ ) between BF% and absolute  $T_{re}$  at the end of LOW 1. A **0.5°C** reduction in  $T_{re}$  below initial resting values was observed in a leaner sub-group of the sample ( $n=4$ : BF **12.3±2.3** %) at the end of LOW 1.  $T_{sk}$  was lower throughout **C** ( $p<0.01$ ) and at the end of LOW 1 was **19.86±0.48°C** and **28.12±0.27°C** in **C** and **N**, respectively. There was a significant inverse correlation ( $r=-0.815$ ;  $p<0.01$ ) between BF% and the difference in VO<sub>2</sub> in **C** compared with **N** during LOW 1. There was no environmental influence on respiratory exchange ratio (mean for HIGH: **N**; **0.91±0.01** vs **C**; **0.91±0.01**, and mean for LOW: **N**; **0.80±0.02** vs **C**; **0.81±0.02**), ventilatory equivalent and HR (mean for HIGH: **N**; **145.32±4.3** vs **C**; **142.1±4.2**, and mean for LOW: **N**; **105.7±3.9** vs **C**; **102.9±3.9** beats·min<sup>-1</sup>).

There was no effect of environment on blood glucose, free fatty acids, glycerol,  $\beta$ -hydroxybutyrate, and plasma adrenaline and insulin concentrations. During HIGH, blood lactate and plasma noradrenaline were the same between environments, however at the end of LOW 1, lactate ( $p<0.05$ : **N**; **0.9±0.1** vs **C**; **1.5±0.1** mmol·l<sup>-1</sup>) and plasma noradrenaline ( $p<0.01$ : **N** **2.9±0.3** vs **C**; **8.3±1.1** pmol·ml<sup>-1</sup>) were higher in **C** compared with **N**.

## CONCLUSIONS

The experimental model was successful in reducing the  $T_{re}$  response to prolonged high and low intensity walking exercise. The effectiveness of the cooling stimulus was confirmed by the low  $T_{sk}$  values and the pronounced activation of the sympathetic nervous system, as evidenced by the high noradrenaline concentrations during low intensity exercise.

In some cases a fall from initial resting  $T_{re}$  occurred during low intensity exercise, especially in those with low body fat content. These leaner subjects had an enhanced heat production in the cold condition. Although not quantified, observation of the subjects coupled with reported shivering suggests that the enhanced metabolic demands of shivering thermogenesis in the non-exercising musculature is likely to be the principal contributor to this increased oxygen cost of low intensity exercise. This finding is consistent with other studies that have observed an increase in the oxygen cost of low intensity exercise in the cold (for review see 4). The fall in  $T_{re}$  in leaner individuals exercising in the cold suggests that heat production due to the metabolic demands of exercise and shivering is insufficient to offset heat loss to the environment. As three of the leanest subjects were unable to complete the cold condition it is possible that excessive heat loss as a consequence of lack of insulating fat is an important factor contributing to exercise performance in the cold.

There appears to be no general consensus in the literature regarding fuel utilisation during exercise in the cold. The present investigation found no environmental effect on exercise metabolism, although higher lactate levels during low intensity exercise may reflect a higher anaerobic contribution to energy demands.

Ethical approval was granted for this study by the APRE Ethics Committee.

## REFERENCES

1. Pugh, L.G.C.E. 1966, Accidental Hypothermia in Walkers, Climbers, and Campers: Report to the Medical Commission on Accident Prevention, *Brit. Med. J* 1, 123-129.
2. Pugh, L.G.C.E. 1967, Cold Stress and Muscular Exercise, with Special Reference to Accidental Hypothermia, *Brit. Med. J* 2, 333-337.
3. Hampton, I.F.G. and Knibbs, A.V. 1986, Study of exposure/exhaustion in man - Final report on APRE Contract No. SLC6c/544.
4. Doubt, T.J. 1991, Physiology of Exercise in the Cold, *Sports Medicine* 11(6), 367-381.