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REVIEW

Physiological limits to exercise performance in the heat

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KEYWORDS
Exercise physiology;
Heat stress

Summary Exercise in the heat results in major alterations in cardiovascular, thermoregulatory, metabolic and neuromuscular function. Hyperthermia appears to be the key determinant of exercise performance in the heat. Thus, strategies that attenuate the rise in core temperature contribute to enhanced exercise performance. These include heat acclimatization, pre-exercise cooling and fluid ingestion which have all been shown to result in reduced physiological and psychophysical strain during exercise in the heat and improved performance.

Contents

Introduction

The increased metabolic heat production associated with strenuous exercise, in combination with impairment of heat dissipation by elevated environmental temperature and/or humidity, creates a major physiological challenge for the exercising athlete. The eminent cardiovascular physiologist Loring Rowell stated that ''*Perhaps the greatest stress ever imposed on the human cardiovascular system (except for severe hemorrhage) is the combination of exercise and hyperthermia. Together these stresses can present*

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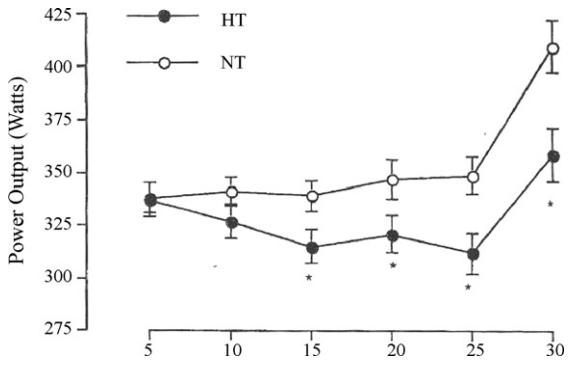

Figure 1 Power output during a 30 min cycling time trial at 32 °C (HT) or 23 °C (NT) in elite road cyclists. Values are means ± S.E. ($n = 11$). (*) Denotes different from NT, $P < 0.05$. From Tatterson et al. (2000).

life-threatening challenges, especially in highly motivated athletes who drive themselves to extremes in hot environments''.[1] Accordingly, exercise performance is reduced and the risk of heat injury is increased when environmental heat stress accompanies strenuous exercise. Laboratory-based studies have documented reduced endurance exercise capacity, as measured by time to fatigue,[2,3] and performance (Fig. 1)[4] under hot conditions. Furthermore, pre-exercise heating results in reduced endurance exercise tolerance.[5] Similar heat-induced reductions in performance are observed during high intensity, sprint exercise.[6,7] Fewer studies have been conducted under field conditions, but heat stress does contribute to reduced marathon running performance[8] and a recent report suggested that marathon finishing times were increased by 2—3% when WBGT exceeded 20 °C.[9]

Physiological and metabolic factors in fatigue

There are potentially several physiological and metabolic factors contributing to the exaggerated fatigue experienced during exercise in the heat. These include alterations in energy metabolism, cardiovascular function and fluid balance, and central nervous system function and motor drive. While it is likely that they all contribute in some way, a common element in fatigue during exercise in the heat appears to be a critically high core temperature, perhaps secondary to an inability of a limited cardiac output to maintain cutaneous perfusion for heat loss.

Metabolism

Muscle glycogen depletion and hypoglycemia have long been associated with fatigue during prolonged, strenuous exercise. During exercise in the heat, the rate of muscle glycogen degradation is significantly increased (Fig. 2)[3,10,11] with a concomitant increase in both carbohydrate oxidation and lactate accumulation. Mechanisms thought to be responsible for the enhanced muscle glycogenolysis include, but may not be limited to, elevated circulating adrenaline and increased muscle temperature.[12] There is an exaggerated hyperglycemia during exercise in the heat due to a greater liver glucose output, without any change in the exercise-induced increase in peripheral glucose uptake.[13] Despite the greater mobilization and utilization of carbohydrate substrates during exercise, carbohydrate depletion is not the cause of fatigue during exercise in the heat since muscle glycogen stores remain high,[3] and the total amount of carbohydrate oxi-

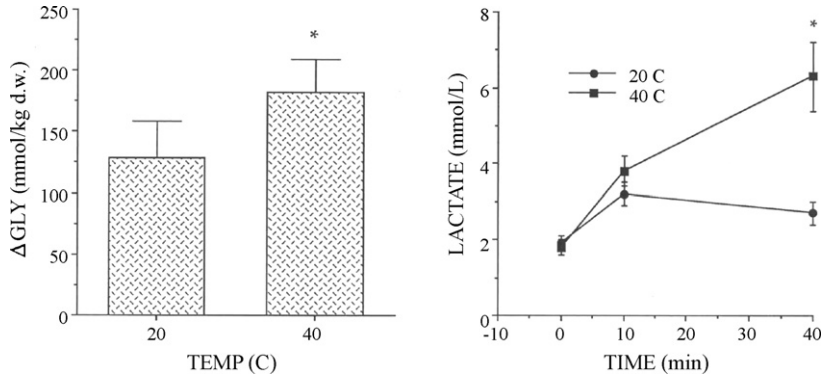

Figure 2 Net muscle glycogen utilisation (left panel) and blood lactate accumulation (right panel) during exercise at ~70% VO_2 peak in trained men at 20 and 40 °C. Values are means ± S.E. ($n = 6$—13). (*) Denotes different from 20 °C, $P < 0.05$. Data from Febbraio et al. (1994).