A. Casey • A.H. Short • S. Curtis • P.L. Greenhaff

The effect of glycogen availability on power output and the metabolic response to repeated bouts of maximal, isokinetic exercise in man

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Abstract The relationship of glycogen availability to performance and blood metabolite accumulation during repeated bouts of maximal exercise was examined in 11 healthy males. Subjects performed four bouts of 30 s maximal, isokinetic cycling exercise at 100 rev·min⁻¹, each bout being separated by 4 min of recovery. Four days later, all subjects cycled intermittently to exhaustion [mean (SEM) 106 (6) min] at 75% maximum oxygen uptake (V̇O₂max). Subjects were then randomly assigned to an isoenergetic low-carbohydrate (CHO) diet [7.8 (0.6)% total energy intake, n = 6] or an isoenergetic high-CHO diet [81.5 (0.4)%, n = 5], for 3 days. On the following day, all subjects performed 30 min cycling at 75% V̇O₂max and, after an interval of 2 h, repeated the four bouts of 30 s maximal exercise. No difference was seen when comparing total work production during each bout of exercise before and after a high-CHO diet. After a low-CHO diet, total work decreased from 449 (20) to 408 (31) J·kg⁻¹ body mass in bout 1 (P < 0.05), from 372 (15) to 340 (18) J·kg⁻¹ body mass in bout 2 (P < 0.05), and from 319 (12) to 306 (16) J·kg⁻¹ body mass in bout 3 (P < 0.05), but was unchanged in bout 4. Blood lactate and plasma ammonia accumulation during maximal exercise was lower after a low-CHO diet (P < 0.001), but unchanged after a high-CHO diet. In conclusion, muscle glycogen depletion impaired performance during the initial three, but not a fourth bout of maximal, isokinetic cycling exercise. Irrespective of glycogen availability, prolonged submaximal exercise appeared to have no direct effect on subsequent maximal exercise performance.

Key words Carbohydrate • Fatigue • Ammonia • Lactate

Introduction

Skeletal muscle contraction is fuelled by energy released from the dephosphorylation of adenosine triphosphate (ATP). The store of skeletal muscle ATP is rapidly utilised and has to be continually resynthesised for muscle contraction to be sustained. During short-term exercise of maximal intensity, almost all ATP resynthesis is achieved by the anaerobic degradation of intramuscular phosphocreatine (PCr) and glycogen stores (Hultman et al. 1990). Furthermore, from the data of Jones et al. (1985) and McCartney et al. (1986), it has been calculated that over the course of 30 s of maximal, isokinetic cycling exercise at 60–100 rev·min⁻¹, the contribution of glycogen to anaerobic ATP provision is four-fold greater than that of PCr, and is as much as nine-fold greater at 140 rev·min⁻¹ (Hultman et al. 1991). On this basis, it would appear that the capacity to sustain maximal muscle force generation is likely to be influenced by muscle glycogen availability.

However, data relating to the effect of glycogen availability on performance during maximal exercise are equivocal. Some authors have demonstrated that a pre-exercise reduction in muscle glycogen concentration can impede subsequent high-intensity exercise performance (Maughan and Poole 1981), but it has been suggested that this may be a result of the exercise undertaken to deplete muscle glycogen stores rather than glycogen availability per se (Young and Davies 1984). Conversely, it has been reported that a reduction in glycogen availability does not influence performance (Symons and Jacobs 1989) or glycogenolysis (Ren et al. 1990) during short-term, intense exercise. In both of these latter studies, however, the pre-exercise muscle glycogen concentration was still relatively high [mean (SEM), 153 (60) and 155 (19) mmol glucose units·kg⁻¹ dry muscle, respectively], and therefore the reported findings might have been expected. Performance of high-intensity exercise lasting approximately 5 min has
been shown to both improve (Maughan and Poole 1981) and remain unchanged (Greenhaff et al. 1987) as a result of increasing glycogen availability via dietary manipulation.

The aim of the present experiment, therefore, was to investigate the effect of glycogen availability on performance and metabolite accumulation during repeated bouts of maximal, isokinetic cycling exercise in man. More specifically, the experiment was performed under conditions where the exercise undertaken to deplete muscle glycogen was the same across experimental groups, and where muscle glycogen concentration was reduced to a very low level prior to maximal exercise.

**Methods**

**Subjects**

Twelve healthy, physically active male subjects gave their written consent to take part in the present study which was approved by the University of Nottingham Medical School Ethical Committee. One subject was unable to complete the study due to illness. Mean (SEM) age, height and body mass of the remaining 11 subjects was 25 (1) years, 178 (2) cm and 73.4 (3.2) kg, respectively. Prior to beginning the study, all subjects participated in a routine medical examination.

**Protocol**

Before the study began, all subjects were thoroughly familiarised with maximal exercise procedures to be used in the present study and all had their maximal oxygen uptake ($\dot{V}O_{2\text{max}}$) determined and verified using an electrically braked cycle ergometer (Lode N.V. Instrumenten, Groningen, Holland) and a discontinuous exercise protocol. The latter measurement was subsequently used to assign subjects to experimental groups.

The study began after a 3-day period during which subjects were matched in terms of their $\dot{V}O_{2\text{max}}$; one member of each pair was randomly assigned to two different dietary intervention groups. This was done in an attempt to ensure that exercise undertaken to deplete muscle glycogen would be similar across experimental groups. At exhaustion, one of the two groups proceeded to consume a prescribed low-carbohydrate (CHO) diet (< 10% total energy intake from CHO, $n = 6$) for the remainder of the day and two subsequent days, and the second group consumed a prescribed high-CHO diet (> 80% total energy intake from CHO, $n = 5$) for the same period (Table 1). Each diet was isoenergetic with each subject's normal diet (Table 1).

On the following morning, subjects reported to the laboratory and performed 30 min cycling at 75% $\dot{V}O_{2\text{max}}$ to ensure glycogen depletion was achieved in those subjects on a low-CHO diet. Consumption of a high-CHO diet following the exhaustive, submaximal exercise ensured this 30-min period of further cycling did not lower the intramuscular glycogen concentration below normal levels in the high-CHO group. The 30-min period of cycling was followed by a recovery interval of 2 h after which the four bouts of 30 s maximal exercise were repeated (trial 3; T3).

Before each laboratory visit, subjects fasted overnight, refrained from strenuous exercise and alcohol consumption for 24 h and, unless otherwise instructed, maintained their daily dietary intake as close to normal as possible.

**Blood handling and biochemical analysis**

Before T2 and T3, the subject's hand was heated for a minimum of 15 min in hot water (42°C) and a 21-gauge venous cannula was placed in a superficial vein on the dorsal surface of the hand. Arterialised-venous blood samples (Forster et al. 1972) were obtained at rest before exercise, immediately after each exercise bout, following 2 min of recovery from each bout and following 2 min, 5 min and 10 min of recovery from the final exercise bout.

| Table 1 Analysis of subjects' normal and experimental diets. Values are mean (SEM) for daily intake calculated from records kept for 3 days on a normal diet and from 3 days on a prescribed, isoenergetic low- (n = 6) or high- (n = 5) carbohydrate (CHO) diet. | Percentage of total energy intake (MJ · 24 h⁻¹) |
|---|---|---|---|
| Total energy intake | CHO | Fat | Protein |
| Normal | 13.20 (0.49) | 60.0 (2.6) | 21.3 (1.9) | 18.8 (0.9) |
| Low CHO | 13.27 (0.48) | 7.8 (0.6) | 62.7 (0.9) | 29.6 (1.0) |
| Normal | 13.63 (0.82) | 67.1 (1.6) | 18.7 (1.1) | 14.1 (0.6) |
| High CHO | 13.64 (0.81) | 81.5 (0.4) | 7.6 (0.7) | 10.9 (0.3) |

**Fig. 1A, B** Average power production [watts · kg⁻¹ body mass (BM)] during four bouts of 30 s maximal, isokinetic cycling exercise. Exercise was performed after a normal (T2) and a low (T3) carbohydrate (CHO) diet (A) and after a normal (T2) and a high (T3) CHO diet (B). Each bout of exercise was performed at 100 rev · min⁻¹ and separated by 4 min of passive recovery. Values represent mean (SEM).