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ERGOGENIC DEMANDS OF A 24 HOUR CYCLING EVENT

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ABSTRACT

The maximal aerobic performance ($\text{VO}_2 \text{ max}$) and energy costs of cycling at various power outputs and equivalent road speeds of a highly trained endurance cyclist (age 23.4 yrs, height 1.95 m, weight 73.1 kg), were measured in the laboratory on an eddy-current cycle ergometer, and the physiological responses related to determinations made during a 24 h cycling time trial event, using continuous ECG recording from which estimates of ergogenic demands were obtained. The cyclist covered a distance of 694 km during the event at an average speed of 28.9 km.h^{-1} which corresponded to an equivalent oxygen cost of $38.5 \text{ ml.kg}^{-1} \text{ min}^{-1}$ and represented approximately 55% of his $\text{VO}_2 \text{ max}$. During the event, the cyclist expended an estimated 82,680 kJ of energy, of which approximately 44,278 kJ (54%) were supplied by repeated feedings of liquids, solids and semi-solids and some 38,402 kJ (46%) came from the stored energy reserves which resulted in a 1.19 kg loss of body weight during the event. The energy demands of the activity were more than three times greater than the highest recorded values of severe industrial work, and similar to the hourly rates of expenditure of shorter duration competitive events, but above the highest values reported over other extreme endurance events over the same period of time. The results thus represent near maximal levels of sustainable ergogenic effort by man over a complete 24 h cycle.

Key words: Cycling, Ultra-distance, Physiological, Nutritional demands.

INTRODUCTION

Investigations of the ergogenic demands and nutritional requirements of prolonged endurance exercise have been the subject of many laboratory based trials aimed at optimising the physiological responses of man to several hours of continuous activity (Thomas, 1971; Thomas and Reilly, 1975; Brooke et al, 1975; Costill et al, 1976; Ivy et al, 1979 and White and Ford, 1983 and 1984). However, with the exception of the studies in

runners (Lloyd et al, 1977; O'Hara et al, 1977 and Davies and Thompson, 1979) and soccer players (Reilly and Walsh, 1981), there has been little attention to the study of extreme endurance performance under actual competitive conditions. Furthermore, even in these most recent studies the emphasis has been largely upon the work performance demands rather than the nutritional requirements of the event.

Therefore in view of the increasing popularity of "ultra-distance" competitive events but relative lack of attention focused upon the study of the specific

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demands of such activity, the present investigation was undertaken in order to estimate the relative aerobic demand, energy expenditure and nutritional intake of a racing cyclist involved in a 24 h road race event.

METHODS

The performance of one competitor who participated in a national 24 hour championship cycle time trial event was continuously monitored during the actual event. All time keeping and distance recording was conducted by the Road Time Trials Council officials who were strategically located on an accurately measured and well-established "open" road race course. The road circuit consisted of over 800 km of public highway class 'A' and 'B' roads and incorporated undulating terrain between 0-50 m elevation above sea level over the first 137 km of the course with the remainder between 50-100 m above sea level.

Environmental conditions reflected typical seasonal (July) characteristics for northern Britain with low (night) and high (day) temperatures of 11°C and 16.5°C respectively. Prevailing winds consisted of light W/NW breeze at 12.9-16.5 km.h⁻¹ which changed to a fresh W/NW wind ≥ 24.2 km.h⁻¹ during the last 5 hours of the event. Light drizzle lasting approximately 30 mins occurred between 02.00 and 03.00 hr associated with the passage of a weak cold front during the night, but other than the second weather front which brought the fresh winds during the latter part of the race, no adverse weather conditions were associated with the event, thus the environmental conditions were considered ideal for the event.

The nutritional requirements of the subject were supplied by a mobile feeding team who attended him throughout, according to the RTTC rules on 24 hr road race events. All the necessary nutritional materials were supplied according to a pre-determined schedule as well as "on demand" feeding by the subject himself. Liquids (a commercial sports drink, sweetened tea, peppermint cocktail and assorted fruit juices), as well as semi-solids (rice pudding and fruit cocktail) were supplied in standard plastic feeding bottles, whereas solids (fruit, sweet-snacks and sandwiches) were delivered using musette containers. These techniques allowed the precise determination of volumes and weights of materials ingested and the subsequent estimation of the energy content which was determined by the use of standard food tables (Paul and Southgate, 1978).

Physiological assessment was accomplished throughout the event by continuous monitoring of the subject's heart rate using an Oxford 24 hour tape recording system (Model MR14; Oxford Medical Systems, Abingdon, England) which was conveniently located in a weather-proof pack contained in the subject's racing jersey pocket. Minute averaged heart rates were used as

a basis for the calculations of physiological costs and estimated energy expenditure rates of the activity involved. Prior to the event, the subject undertook a comprehensive series of clinical diagnostic exercise evaluations, as well as functional performance assessments using standardised techniques which have been described previously (White et al, 1982). The linear relationship between heart rate and oxygen consumption established from the laboratory tests (Fig. 1) was used to estimate the oxygen costs of the activity during the event. Following the determination of the energy costs of graded exercise activity using the non-protein respiratory exchange ratio (Carpenter, 1964), the established linear regression of heart rate and energy expenditure (Sengupta et al, 1979), also demonstrated in the present study (Fig. 1), was used to estimate the energy equivalent of work performed during the 24 hour event. In this way heart rate responses reflected the physiological demand and energy cost incurred by the activity.

Fig. 1: Relationship between heart rate, oxygen consumption and energy expenditure during graded exercise.

RESULTS

The speed profile of the subject over the 24 h period is presented in Fig. 2 along with the temporal interruptions in the performance required by the necessary mechanical maintenance, body care and toiletry activities. There was a gradual decline in the cumulative average speed during the event and although the timed

Fig. 2: Speed profile during the 24 hour cycle road race.

interval averaged speeds showed a similar decrement overall, there were considerable speed variations especially between 15-18 h which were attributed to both terrain and environmental influences as well as stoppages. It is interesting to note, however, that the first 161 km (100 m) of the event were covered in a time and at an average speed which was approximately 90% of the subject's previous personal best performance for that distance (Table I).

TABLE I

Physical performance characteristics of the subject who participated in a 24 hour cycle road race event.

Physical Characteristics

Age: 24.3 yrs Height: 1.95 m
Weight: 73.13 kg Body Fat: 8.2% (estimated)

Maximal Exercise Performance Characteristics

Heart rate (b.min⁻¹) 189.0
Ventilation volume (L.min⁻¹) 175.1
Oxygen consumption (ml.kg⁻¹ min⁻¹) 69.9
Oxygen pulse (ml.beat⁻¹) 27.0
Respiratory exchange ratio 1.05
Absolute power (kpm.min⁻¹) 2781.0
Relative power (kpm.min⁻¹ kg⁻¹) 38.0

Personal Best Cycle Road Race Performances

EVENT (miles) (km)	TIME (hrs. min. sec.)	AVERAGE SPEED	
		(mph)	(km.h ⁻¹)
5 8.05	0 : 11 : 07	27.0	43.5
10 16.10	0 : 23 : 41	25.3	40.7
25 40.25	0 : 58 : 43	25.5	41.1
50 80.50	2 : 02 : 07	24.6	39.6
100 161.00	4 : 23 : 17	22.8	36.7

The physiological profile of the subject over the 24 h period is presented in Figure 3. There was a progressive decline in the absolute and relative (% maximal) minute average heart rates during the event with a corresponding reduction in the estimated oxygen consumption rates as well as %VO₂ max utilised. Minor variations in heart rate and oxygen consumption levels did not affect the overall decline in both the measured and predicted parameters which tended to reflect the cumulative speed profile, and were therefore open to terrain and environmental influences as well as stoppages, all of which contributed to the observed variability.

Nevertheless it could be observed that there was a clear trend of a decline in both determined heart rate and derived oxygen consumption parameters during the first 6 h of the event, with heart rates reduced from ~165 b.min⁻¹ (88% HR max) to ~140 b.min⁻¹ (74% HR max) and estimated oxygen consumption reduced from ~52.5 ml.kg⁻¹ min⁻¹ (75% VO₂ max) to ~38 ml.kg⁻¹ min⁻¹ (55% VO₂ max). This was followed by a period of relative stability with minor oscillations in the physiological parameters between 6-18 h in which heart rate fluctuated around 142 b.min⁻¹ (75% HR max) and estimated oxygen consumption at 39 ml.kg⁻¹ min⁻¹ (56% VO₂ max). Finally there was a further marked decline during the last 6 h of the event in which heart rates reduced from ~132 b.min⁻¹ (70% HR max) to ~120 b.min⁻¹ (63% HR max) and estimated oxygen consumption reduced from ~35 ml.kg⁻¹ min⁻¹ (50% VO₂ max) to ~25 ml.kg⁻¹ min⁻¹ (35% VO₂ max). The overall averages for the physiological parameters throughout the 24 h event involved heart rates of ~142 b.min⁻¹ (75% HR max) and estimated oxygen consumption of ~38.5 ml.kg⁻¹ min⁻¹ (55% VO₂ max).

Fig. 3: Physiological event profile during the 24 hour cycle road race.

Using the original heart rate and energy expenditure regression equation generated from laboratory tests, the estimated energy expenditure rates derived from heart rate measures taken during the event were calculated. During the first 6 h energy expenditure declined from $\sim 82 \text{ kJ.min}^{-1}$ to 58 kJ.min^{-1} . Between 6-18 h energy expenditure fluctuated at $\sim 62 \text{ kJ.min}^{-1}$. Finally during the last 6 h of the event energy expenditure declined further from $\sim 52 \text{ kJ.min}^{-1}$ to 40 kJ.min^{-1} . The overall average throughout the 24 h event involved an energy expenditure rate of $\sim 58 \text{ kJ.min}^{-1}$.

24 h period is presented in Table II which represents the relative contribution of liquids, semi-solids and solids to the total energy intake during the event. Pre-event feeding of liquid and semi-solid nutritives accounted for approximately 5% of the total energy intake. Subsequently the contribution of liquids became increasingly important during the event, particularly during the period 18-24 h. The contribution of solid foods was most pronounced during the period 12-18 h. Whereas semi-solids were most evenly distributed over the four sub-divisions of the whole time period.

The nutritional intake profile of the subject over the

The percentage of total energy intake was highest for

TABLE II
Nutritional intake during a 24 hour cycling road race event (one subject: J.A.S.)

Nutritional Mode		Liquids			Solids				Semi-Solids			Totals			
Time Intervals	Vol. (ml)	Energy (kJ)	(kCal)	% Total Energy	Wt. (gm)	Energy (kJ)	(kCal)	% Total Energy	Wt. (gm)	Energy (kJ)	(kCal)	% Total Energy	Energy (kJ)	(kCal)	Energy (%)
Pre-Event (2 hrs)	300	565	(135)	1.3	—	—		—	420	1674	(400)	3.9	2239	(536)	5.2
0-6 hrs	640	1507	(361)	3.4	308	2177	(521)	4.9	1060	4194	(1003)	9.4	7878	(1885)	17.7
6-12 hrs	1540	3571	(854)	8.0	225	3998	(956)	9.0	760	3148	(753)	7.0	10717	(2564)	24.0
12-18 hrs	1050	2846	(681)	6.4	1030	8037	(1922)	18.0	1050	4186	(1001)	9.9	15069	(3605)	34.3
18-24 hrs	1800	4792	(1146)	10.7	75	837	(200)	1.9	680	2746	(657)	6.2	8375	(2004)	18.8
Totals	5330	13281	(3177)	29.8	1638	15049	(3600)	33.8	3970	15948	(3824)	36.4	44278	(10593)	100.0
Energy by Wt. & %	5,480 kg			50%	1,638 kg			14.8%	3,970 kg			35.2%	11,088 kg		100%

the semi-solids (36.4%), followed by solids (33.8%) and liquids (29.8%). Furthermore the percentage of total energy intake over the event rose steadily during the first three time periods; 0-6 h (17.7%), 6-12 h (24.0%) and 12-18 h (34.3%), followed by a return close to the initial intake level during 18-24 h (18.8%).

Overall 11.09 kg of nutritional materials were ingested during the 24 h period, of which carbohydrates (60%), fats (30%) and proteins (10%) contributed a total of 44,278 kJ energy equivalent or 54% of the estimated energy requirement of the event. Nevertheless, this represented a short-fall of approximately 38,402 kJ from the estimated 82,680 kJ energy expenditure incurred by the performance. The difference could be explained by the observed net body weight loss of 1.19 kg in the subject which could have supplied the remaining 46% of the estimated energy requirement of the activity involved.

DISCUSSION

The subject who took part in the study was representative of top class road race cyclists (category 1: British Cycling Federation racing standard), with a VO_2 ($69.9 \text{ ml.kg}^{-1} \text{ min}^{-1}$) comparable to other ultra-distance athletes and a previously established record of endurance performance (Table 1), although not including a 24 h event.

The temporal profile of the race demonstrated some similarities with the only other major study of 24 h endurance performance by two "ultra-distance" runners (Davies and Thompson, 1979), in that speed declined as a function of distance covered, and the estimated average level of aerobic performance of $38.5 \text{ ml.kg}^{-1} \text{ min}^{-1}$ (55% VO_2 max) overall was slightly higher than the reported values observed in the runners of the previous study who averaged 36.4 and $35.3 \text{ ml.kg}^{-1} \text{ min}^{-1}$ which represented 47% and 51% of their respective VO_2 max values. Correspondingly, the total estimated energy expenditure of the present study of 82,680 kJ was somewhat higher than that reported by Davies and Thompson (1979) at 77,829 kJ in the runner who recorded the greatest distance.

Other attempts to document the physical requirements in "ultra-distance" eventing have been largely restricted to the popular press media rather than sports research literature, so that the present and the previous study represent some agreement in terms of the physiological responses of highly trained endurance athletes to

competitive 24 h racing albeit from two contrasting modes of activity.

The nutritional intake of the subject during the 24 h period of 44,278 kJ was considerably higher than previously reported values of 30,870 kJ per day during a continuous walking exercise task of 100 h (Thomas and Reilly, 1979), and more than three times greater than the highest values previously reported by the most demanding industrial activity (Lundgen, 1946). Moreover the level of energy intake observed in the present study was more than double the daily average intakes reported for international class cyclists during a survey of representative training periods reported by Stordy (1980) (19,238 kJ/day) and Barry et al (1981) (17,050 kJ/day), and similar to the hourly rates of energy expenditure reported by Hedman (1957) in a competitive skiing endurance event ($\sim 4,186 \text{ kJ.hr}^{-1}$ over 7 hours). Furthermore the percentage of total energy derived from proteins (10%), fats (30%) and carbohydrates (60%) was markedly shifted towards carbohydrate intake compared with the pattern of intake of the three major nutrient categories reported by Barry et al (1981) (proteins 13.4-15.5%, fats 39.3-42.4% and carbohydrates 43.8-45.8%).*

Not surprisingly the continuous nature and hence energy requirement of the activity involved in the present study, together with the need to supply nutrients in a palatable form which could be easily accepted by the digestive system, favoured the use of carbohydrates in liquid and semi-solid form in order to maximise the uptake of a readily usable form of energy substrate (Thomas, 1971; Brooke et al, 1975; Costill et al, 1975 and Ivy et al, 1979). Furthermore, in order to offset fluid losses incurred in prolonged endurance activity which may lead to both thermal and cardio-respiratory disturbance (Costill and Fink, 1974 and Costill et al, 1976), it was necessary to provide a relatively large volume of liquid to overcome the evaporative and respiratory losses, while at the same time providing a suitable medium for nutrient delivery (White et al, 1983 and 1984). Nevertheless, it was only possible to supply a little more than half (54%) of the total energy required for the performance, so that the remainder (46%) was contributed by the subject's own energy reserves resulting in an equivalent (net) weight loss of almost 1.2 kg.

It was concluded that while the performance of the subject was below that of the event record for 816 km (507 m), it was representative of the standard achieved by top 24 h cycling road race specialists and thus approximates the upper limit of physiological endurance for the mode of exercise concerned. Furthermore the study adds to the fundamental knowledge concerning the physiological and nutritional demands of 24 h "ultra-distance" eventing and thus provides

* 44,278 kJ $\sim$ 10,580 kCals
30,870 kJ $\sim$ 7,380 kCals
19,238 kJ $\sim$ 4,600 kCals
17,050 kJ $\sim$ 4,070 kCals
4,186 kJ $\sim$ 1,000 kCals/hr

information on those necessary parameters not only required to improve performance, but possibly reduce the risks of impaired performance.

ACKNOWLEDGEMENTS

The authors would like to thank the Mersey Road

Cycling Club and Road Time Trials Council race officials, technicians of the Human Performance Laboratory of Salford University and the Department of Cardiology at Wythenshawe Hospital, as well as the members of "The Establishment" feeding team and most of all the subject who participated in the study.

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BOOK REVIEW

Title: EMERGENCIES IN GENERAL PRACTICE
Authors: A. J. Moulds, P. B. Martin and T. A. I. Bouchier-Hayes
Publisher: George A. Bogden, Ridgewood, New Jersey, USA, 1983 and in UK: MTP Press, Lancaster. ISBN 0-942068-07-6
Price: £10.95 **215 pages** **Index** **Hard cover**

I am keeping my review copy of this book in my car, easily accessible, and will probably buy another for the surgery. It is written by three general practitioners for general practitioners and covers most of the emergencies, trivial as well as life-endangering, that one meets in practice. The opening chapters give general advice on the doctor's legal and moral obligations, how to manage telephoned requests, drugs and equipment likely to be needed in an emergency, and the general management of paediatric crises. This is the longest chapter in the book, and a very valuable one. The remainder of the book lists, in alphabetical order, urgent conditions in the various systems, starting with cardiological emergencies. Each section of each chapter starts with the most likely incoming telephone request, the questions that should be asked, the differential diagnosis, then in a conspicuous box, the advice given over the telephone, and the management of the condition; advice and attend surgery the next day; visit and treat or prescribe; admit; what to tell the patient and the relatives — all good sound practical instructions based on experience.

For future editions a few points need to be added or amended in light of recent practice. In the chapter on obstetric and gynaecological emergencies is a section on contraceptive problems, and though "missed pill", breakthrough bleeding and coil falling out are mentioned, the real emergency of post-coital contraception is omitted. The new amendments to the Mental Health Act relating to admission under a section need updating.

Although Lt.Col. Bouchier-Hayes has contributed several articles to this journal, there is little direct sports-related emergency treatment in this book, but most sports specific injuries are from overuse rather than acute trauma. I would regard the book as an essential part of the kit of any doctor accompanying a team on a tour, especially overseas. Although one would hope that the management of most of the emergencies dealt with would be within the scope of an experienced GP, the value of the book would be for the hospital doctor coping with conditions in his team outside his field of specialisation. The first aid advice and home management of the less serious illnesses given in the book could also be a big help to the team physiotherapist on tour without a doctor. It must be borne in mind, however, that a doctor is not recognised as such when in another country, and that transporting controlled drugs across a frontier usually requires export and import licences from both countries concerned.

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