J. A. White

G. Quinn

M. Al-Dawalibi

J. Mulhall

SEASONAL CHANGES IN CYCLISTS' PERFORMANCE

PART I

THE BRITISH OLYMPIC ROAD RACE SQUAD

J. A. WHITE, PhD*, G. QUINN, MA*, M. AL-DAWALIBI, MSc** and J. MULHALL, AIMLS†

Human Performance Laboratory, Salford University, Salford, M5 4WT, Lancs.

**Lecturer, **Research Student, †Technical Officer*

ABSTRACT

British Olympic road squad cyclists were monitored during the 1980 racing season to evaluate training for the Moscow Games. Riders demonstrated reductions in body fat index, % body fat and endomorphy ($p > .05$). Graded exercise, using a "Racermate" wind load simulator/racing cycle ergometer system, showed reduced cardiovascular demands to warm-up exercise, and increased cardiovascular index, VO_2 maximum, aerobic/anaerobic threshold shifts during maximal exercise (NS), with no changes in gearing, equivalent road speed, absolute/relative power output and leg power.

Compared with "non-select", "select" riders demonstrated lower body fat index, % body fat and endomorphy ($p > .05$), higher Hb and PCV % ($p > .05$) and elevated neuroticism and extraversion ($p > .05$). Furthermore, "select" riders demonstrated lower HR and CV index during warm-up exercise ($p > .05$), and elevated CV index, VO_2 maximum, aerobic/anaerobic thresholds during maximal exercise ($p > .05$), resulting from higher gearing, equivalent road speed and absolute/relative power output ($p > .05$).

Key Words: Seasonal changes, Performance, Road race cyclists.

INTRODUCTION

Several studies have documented the physiological characteristics of elite endurance road race cyclists (Bonjer, 1979; Burke et al, 1977; Hagberg, Giese et al, 1979; Hagberg, Mullin et al, 1979; Saltin and Åstrand, 1967; Stromme et al, 1977). However, with the exception of longitudinal studies on young cyclists (Placheta et al, 1973(a), 1973(b) and Placheta, 1980) there has been comparatively little attention devoted to the study of the seasonal changes in both the general and specific performance characteristics of elite cyclists participating

in road race cycle training and competition.

Initially, a total group of 16 riders, comprising the squad, were tested during the January assessment, prior to the start of the competitive racing season. From the total group, sub-groups of four "select" and 12 "non-select" riders were established as a result of competitive selection procedures employed during the racing season. Subsequently, 14 of the original 16 riders were available for assessment during the early season period of

March, with sub-groups of three "select" (one "select" rider being unavailable for retesting) and 11 "non-select" riders. Finally, the assessment during the mid-season period of July was conducted only upon the "select" riders who had been nominated as a result of their racing performances over Olympic Trials selection series, and included the four riders who had been tested previously during the January and March assessments, together with one additional rider, making a sub-group of five riders included in the final Olympic select squad of seven members. The two further members of the final road squad, representing Great Britain in Moscow in 1980, were not included in the overall monitoring/assessment scheme.

Test procedure: Road Squad aerobic power (VO_2 max) test.

All riders, included in the scheme, were assessed on a variety of general anthropometric, lung function, personality, haematological and resting cardiovascular indices, before undertaking specific tests designed to assess selected physiological components related to the aerobic power requirements of road race cycling.

METHOD

A. General measures

Anthropometric determinations included height, weight, subcutaneous fat skinfold thickness at four sites (biceps, triceps, subscapular and supra-iliac) which yielded a total skinfold index (mm) and an estimate of the percentage of total body fat according to Durnin and Womersley (1974). Somatotype classification was carried out, using Heath and Carter (1967). Lung function analyses incorporated standardised analyses, using a "Vitalograph" spirometer which provided measures of FVC, FEV 1.0

and FEV 1.0%. Haematological variables were determined from venous capillary blood samples obtained by a thumb prick technique and analysed for haemoglobin content and packed cell volume. Resting cardiovascular indices, including heart rate and blood pressures, were recorded, using electrocardiographic and auscultatory techniques, respectively, with the cardiovascular index determined by rate $\times$ pressure product/1000. Personality characteristics were determined by questionnaire techniques to assess personality "traits" using the personality inventory of Eysenck (1962) related to extraversion/introversion and neuroticism/stability dimensions, along with psychological "states" (Zuckerman and Lubin, 1965) related to anxiety ratings at the time of laboratory assessment. Leg power indices were determined, using a modified vertical jump task, which takes into account body weight and height jumped to provide relative power indices.

B. Specific measures

The functional performance characteristics of the road squad riders were assessed during warm-up and maximal exercise conditions, using a recently developed ergometry system (Firth, 1981), which incorporated a "Racermate" wind load simulator (IRB [Import and Export] Limited) fitted to each rider's own road racing cycle, mounted upon a set of steel cycle training rollers, Fig. 1. The resistive force which brakes the rear wheel of the cycle is provided by a geometrically-oriented system of baffles which rotates freely via a roller bearing applied by a constant force (tension bolt) to the rear tyre which is maintained at a standardised pressure of five bars. The resulting effect is to provide both the frictional (road) and drag (air) force components of resistance which normally act upon machine and rider under actual road conditions of cycling. Therefore, by selecting the appropriate gearing ratios, it is possible to vary the work load input/power output demands throughout the range of mechanical and physiological levels of work associated with cycling at varying road speeds.

Warm-up exercise

Warm-up exercise consisted of unloaded exercise on the cycle rollers (without Racermate) at a pedalling frequency of 90 rpm on each rider's smallest gear available (from a combination of largest chain ring and sprocket). Following five minutes of "steady-state" exercise, cardiorespiratory parameters were assessed as outlined below.

Maximal exercise

Maximal exercise consisted of a graded exercise protocol (with Racermate applied) based on each rider's variable gearing ratio, with a three minute incremental increase in gear size (from warm-up exercise gearing combination) at a constant pedal frequency of 90 rpm until standardised maximal respiratory (VO_2 maximum) criteria had

Bicycle Ergometry System

Fig. 1: Bicycle ergometry system.

been achieved. Cardiorespiratory parameters were monitored throughout each staged increase in exercise in order to assess the physiological adjustments made to successive work loads.

Physiological analyses

Cardiovascular indices of work were established by determination of heart rate, systolic blood pressure and cardiovascular index. Heart rates were measured by a standard bipolar cardiometer (Cardionics) and systolic blood pressures, using a "Boso-tron" automated sphygmomanometer (Andrew Stephens Limited). The cardiovascular index of work was recorded in arbitrary rate/pressure units (Bonnardeaux and Bonneau, 1978).

Respiratory indices of work were recorded utilising an on-line gas analysis system (the exercise programme of the Beckman Metabolic Measurement Cart — Beckman MMC). Subjects, wearing a nose clip, breathed via a rubber mouthpiece, through a low resistance valve

(Jakeman and Davies, 1979) attached by flexible plastic piping to the gas analyser. The oxygen and carbon dioxide analysers were previously calibrated against gases of known composition (micro-Scholander). The ventilation volumes were calibrated using a precalibrated syringe. Aerobic and anaerobic thresholds were identified from expired ventilatory responses (Skinner and McLellan, 1980).

Mechanical analyses

Estimates of absolute (m.kg.min^{-1}) as well as relative ($\text{m.kg.min}^{-1}.\text{kg}^{-1}$) power outputs were derived from gearing ratios and pedalling frequencies, along with estimates of equivalent road speeds, using data used to calibrate the "Racermate" wind load simulator (Firth, 1981).

C. Statistical measures

Inferential statistics (Student's t-test with the appropriate degrees of freedom) were used to detect changes

and comparative differences in the general and performance characteristics of the total groups and sub-groups of riders during the various assessment phases of the racing season.

RESULTS

The laboratory findings of the riders during the January, March and July assessments of the 1980 racing season may be reported in terms of:

A. The general (longitudinal) findings observed within the total groups of riders tested in January (N = 16) and March (N = 14).

B. The comparative (cross-sectional) findings observed between the sub-groups of non-select (NS) and select (S) groups of riders during the January (N = 12 vs. N = 4) and March (N = 11 vs. N = 3) assessments, as well as the subsequent changes observed in the S group during the final July (N = 4) assessment, with additional data presented on a sub-group (N = 5) of the final Olympic select squad.

(1) Anthropometric data (Table I)

In the total groups there was a clear trend towards body weight reduction during the racing season, due to

decreased body fat index and estimated body fat percentage, along with somatotype modification in terms of reduced endomorphy, rather than changes in mesomorphy and ectomorphy (Fig. 2). However, the changes were not statistically significant.

In the sub-groups, the S group of riders tended to be smaller and lighter than the NS group, and demonstrated greater weight loss during the racing season, although the differences between the S and NS groups were related to changes in body fat content in the former group which demonstrated lowered body fat index and body fat percentage (both $p > 0.5$, January to March) compared with the NS group. Furthermore, these characteristics were maintained by the S group during the final assessment (July). Somatotype differences between the S and NS groups included lower endomorphy ($p > .05$) and higher mesomorphy and ectomorphy displayed by the S group (see also Fig. 2) which demonstrated a reduction in endomorphy ($p > .05$, January to March). Finally, body composition profiles of the S group remained relatively stable in the July assessment.

(2) Lung function data (Table I)

There were no significant changes in lung function para-

TABLE I

General characteristics of the BCF Olympic road squad cyclists during the 1980 racing season

		JANUARY								MARCH				JULY			
		N = 16		N = 12		N = 4		N = 14		N = 11		N = 3		N = 4		N = 5	
		$\bar{x} \pm SE$		$\bar{x} \pm SE$		$\bar{x} \pm SE$		$\bar{x} \pm SE$		$\bar{x} \pm SE$		$\bar{x} \pm SE$		$\bar{x} \pm SE$		$\bar{x} \pm SE$	
Anthro- pometric																	
Age (yrs)	22.0	0.6	21.3	0.6	22.0	0.6	22.4	0.6	21.8	0.6	22.3	0.8	22.7	0.6	22.8	0.1	
Height (cm)	175.7	1.6	176.3	2.0	173.7	1.3	176.2	1.9	176.8	2.2	174.1	1.9	173.8	1.3	172.7	1.6	
Weight (kg)	69.7	1.6	69.8	1.8	69.3	2.8	68.4	1.6	69.1	1.8	66.0	2.1	66.3	1.9	65.1	1.9	
Body Fat Index (mm)	25.1	1.5	25.5	1.7	24.1	2.7	22.5	1.4	23.3	1.6	19.4*	1.1	21.4	1.8	21.0	1.7	
% Body Fat (Est.)	10.6	0.7	10.7	0.7	10.0	1.3	9.1	0.7	9.6	0.7	7.6*	0.6	8.5	0.9	8.3	0.8	
Endomorphy Factor	2.0	0.2	2.0	0.2	1.8	0.3	1.6	0.1	1.7	0.2	1.3*	0.1	1.6	0.2	1.6	0.2	
Mesomorphy Factor	4.3	0.3	4.0	0.3	4.5	0.4	4.2	0.3	4.0	0.3	5.0	0.6	5.1	0.5	4.7	0.6	
Ectomorphy Factor	2.7	0.2	2.7	0.3	2.5	0.5	2.8	0.2	2.8	0.3	3.0	0.5	2.6	0.4	2.7	0.4	
Lung Function																	
FVC (L)	5.85	0.14	5.85	0.17	5.84	0.19	5.75	0.16	5.76	0.18	5.71	0.25	5.75	0.24	5.68	0.22	
FEV 1.0 (L)	4.94	0.09	4.96	0.10	4.89	0.18	4.97	0.11	4.97	0.12	4.96	0.24	4.86	0.25	4.83	0.23	
FEV %	85.4	1.1	85.2	1.3	86.1	1.6	86.7	1.2	86.7	1.4	86.9	1.0	84.5	2.2	85.0	2.0	

*Significant at the 0.05 level

Fig. 2: Anthropometric characteristics of the BCF Olympic road squad cyclists during the 1980 racing season.

meters in the total groups nor any significant differences observed between the NS and S groups during the racing season.

(3) Personality data

In the total groups there were no significant changes in EPI scores during the racing season. However, the S group demonstrated elevated neuroticism ($p > .05$) compared with normative data in general (Eysenck and Eysenck, 1962) and the NS groups in particular, in the January and March assessments, although scores in the S group in the July assessment were returned towards normative levels (Fig. 3).

(4) Haematological data (Table II)

In the total groups there were no significant changes in haematological parameters during the racing season. However, the S group demonstrated higher haemoglobin ($p > .05$) and packed cell volume ($p > .01$) compared with the NS group in the January assessment. However, these differences were not apparent in the March assessment and haematological parameters in the S group remained stable in the July assessment.

(5) Resting cardiovascular data (Table II)

In the total groups there was a small, but non-significant

Fig. 3: Personality characteristics (EPI dimensions) of the BCF Olympic road squad cyclists during the 1980 racing season.

reduction in heart rate between January and March, but no change in blood pressure during the same period. Similar patterns of cardiovascular responses were observed in the NS and S sub-groups, within no apparent differences between the groups during the racing season, nor significant changes exhibited by the S group in the July assessment.

(6) Warm-up exercise data (Table II)

In the total groups there was a clear but non-significant reduction in submaximal exercise cardiovascular responses during the racing season in terms of lowered heart rate, systolic blood pressure and cardiovascular index between January and March. However, during the same period, there was no change in oxygen consumption values and mechanical indices of work and power in terms of gear size employed and equivalent road speed achieved.

The S group demonstrated lower heart rate and cardiovascular index (both $p > .05$) during submaximal exercise compared with the NS group in the January assessment, and a trend towards lower blood pressure responses. However, such differences were absent in

TABLE II

General characteristics of the BCF Olympic road squad cyclists during the 1980 racing season

	JANUARY						MARCH						JULY					
	N = 16		N = 12		N = 4		N = 14		N = 11		N = 3		N = 4		N = 5			
Variables	$\bar{x} \pm SE$		$\bar{x} \pm SE$		$\bar{x} \pm SE$		$\bar{x} \pm SE$		$\bar{x} \pm SE$		$\bar{x} \pm SE$		$\bar{x} \pm SE$		$\bar{x} \pm SE$			
Haematology																		
Haemoglobin (g.dl.)	15.3	0.3	15.1	0.3	16.1*	0.5	15.2	0.2	15.2	0.3	15.1	0.3	15.2	0.4	15.3	0.4		
PCV (%)	45.8	0.8	45.0	0.9	48.3**	1.3	46.6	0.5	46.7	0.6	46.3	0.5	45.0	0.7	45.6	0.9		
Cardiovascular (Rest)																		
Heart Rate (b.min ⁻¹)	58.9	3.2	59.9	4.0	56.0	3.3	56.0	2.7	56.3	3.1	54.0	3.5	53.0	3.0	51.5	3.0		
Systolic BP (mmHg)	124	2	125	3	123	1	125	1	125	1	125	2	126	2	125	2		
Diastolic BP (mmHg)	75	2	76	3	71	1	74	1	74	1	72	3	69	6	74	3		
Warm-up Exercise																		
Heart Rate (b.min ⁻¹)	118.0	3.3	120.7	3.9	112.0*	4.1	109.4	3.0	109.1	3.6	111.0	2.6	102.0*	2.5	103.4	2.7		
Systolic BP (mmHg)	156	3	158	2	150	7	143	1	144	1	140	2	141	5	141	5		
Cardiovascular Index	18.2	0.5	18.7	0.5	16.6*	0.5	15.7	0.5	15.7	0.6	15.8	0.5	14.4*	0.7	14.6	0.6		
VO ₂ (ml.kg ⁻¹ .min ⁻¹)	27.4	1.0	27.8	1.2	26.1	1.0	26.9	0.9	27.3	1.0	25.5	1.6	24.9	0.7	25.3	0.8		
Gear Size (metres)	1.86	.03	1.88	.04	1.80	.07	1.85	.04	1.86	.04	1.84	.07	1.84	.05	1.87	.06		
Equivalent Road Speed (km.h ⁻¹)	28.5	0.6	28.8	0.6	27.4	1.4	28.3	0.6	28.3	0.6	28.2	1.4	28.2	1.0	28.8	1.0		

*Significant at the 0.05 level

**Significant at the 0.01 level

the March assessment, although the S group demonstrated further reductions in heart rate and cardiovascular index responses (both $p > .05$) to submaximal exercise in the July assessment. Furthermore, the S group displayed marginally lower oxygen consumption values than the NS group in the January and March assessments, which may have been partially attributable to reduced work (gear size) and power (km.h^{-1}) indices in January, but not during March where such indices were almost identical. Finally, in the July assessment, the S groups showed relative stability of both cardiorespiratory and mechanical work and power indices during warm-up exercise.

(7) Maximal exercise data (Table III)

In the total groups there was a clear but non-significant elevation of heart rate, systolic blood pressure and

cardiovascular index responses to maximal exercise, along with increased oxygen consumption, and aerobic and anaerobic thresholds during the racing season. However, such cardiorespiratory adjustments were associated with increased ride time to exhaustion, rather than changes in mechanical work or absolute/relative power indices. Furthermore, leg power indices remained relatively unchanged between January and March.

The S group demonstrated higher systolic blood pressure and cardiovascular index responses (both $p > .05$), as well as elevated VO₂ maximum ($p > .05$), aerobic threshold ($p > .05$) and anaerobic threshold ($p > .01$) responses to maximal exercise, compared with the NS group in the January assessment. Enhanced cardio-respiratory capability was associated with elevated mechanical work (gear size $p > .05$), absolute

TABLE III

Performance characteristics of the BCF Olympic road squad cyclists during the 1980 racing season

Variables	JANUARY						MARCH						JULY			
	N = 16		N = 12		N = 4		N = 14		N = 11		N = 3		N = 4		N = 5	
	$\bar{x} \pm SE$		$\bar{x} \pm SE$		$\bar{x} \pm SE$		$\bar{x} \pm SE$		$\bar{x} \pm SE$		$\bar{x} \pm SE$		$\bar{x} \pm SE$		$\bar{x} \pm SE$	
Maximal Exercise																
Heart Rate (b.min ⁻¹)	187.1	2.6	186.0	2.8	191.0	4.9	191.9	2.7	191.2	3.2	195.0	1.9	186.0	5.3	189.6	6.0
Systolic BP (mmHg)	194	1	193	1	199*	2	204	3	205	3	200	5	193	3	196	3
Cardiovascular Index	36.2	0.6	35.6	0.7	37.9*	0.8	39.2	0.8	39.3	1.0	38.9	0.6	35.9	0.8	37.1	1.4
VO ₂ max (ml.kg ⁻¹ .min ⁻¹)	68.4	1.5	67.0	1.5	72.4*	2.7	72.1	1.9	70.3	2.0	78.6**	0.9	76.0	1.2	77.4	1.7
Total Ride Time (s)	663	39.3	640	50.4	728	31.2	700	30.5	678	35.2	782**	35.0	790	25.3	740	53.0
Aerobic Threshold (s)	281	29.9	240	31.4	405**	15.0	317	29.1	295	31.3	400**	51.9	420	42.4	372	58.2
Anaerobic Threshold (s)	518	37.5	495	48.6	585*	15.0	557	38.5	540	46.4	620	52.9	660	24.5	588	66.5
Gear Size (metres)	2.32	0.04	2.29	0.05	2.43*	0.06	2.32	0.05	2.32	0.05	2.32	0.15	2.45	0.05	2.45	0.04
Equivalent Road Speed (km.h ⁻¹)	43.1	0.8	42.8	0.9	45.6*	1.1	43.1	0.9	43.1	0.9	43.1	2.6	46.5	0.6	46.4	0.4
Power (m.kg.min ⁻¹)	2550	120	2420	140	2860*	190	2460	130	2460	150	2470	410	3000	80	2990	70
Watts	417	19.9	396	22.1	468*	31.5	403	21.5	403	22.6	403	67.5	490	13.5	488	10.6
Relative Power (m.kg.min ⁻¹ .kg ⁻¹)	36.4	1.7	34.9	2.0	41.2**	1.2	36.2	2.0	36.0	2.2	37.0	4.8	45.3	1.0	45.9	0.9
Watts kg ⁻¹	6.0	0.3	5.7	0.3	6.7**	0.2	5.9	0.3	5.9	0.4	6.1	0.8	7.4	0.2	7.5	0.2
Vertical Jump (cm)	38	1	37	1	40	3	37	1	36	2	41	2	38	2	38	2
Leg Power (m.kg.s ⁻¹)	94.6	2.3	93.1	2.3	95.4	4.6	91.5	2.3	90.0	3.1	93.8	3.1	90.8	3.1	88.5	3.1
Watts	931	22.6	916	22.6	939	45.3	900	22.6	886	30.5	923	30.5	893	30.5	871	30.5

*Significant at the 0.05 level

**Significant at the 0.01 level

power (km.h⁻¹ and m.kg.min⁻¹, both $p > .05$) and relative power (m.kg.min⁻¹.kg⁻¹ $p > .01$) indices in the S group, which demonstrated extended, but non-significant, ride time to exhaustion compared with the NS group.

The differences in cardiovascular responses to maximal exercise between the S and NS groups were largely absent in March, although the S group retained

elevated VO₂ maximum and aerobic threshold (both $p > .01$) and a trend towards higher anaerobic threshold values. However, such differences were associated with extended total ride time to exhaustion ($p > .01$) in the S group, rather than differences in mechanical work capability or absolute/relative power indices between the S and NS groups. In July, the S group displayed somewhat reduced cardiovascular responses to maximal exercise, maintained respiratory enhancement and small,

but non-significant, increments in mechanical work and absolute/relative power. Similar performance characteristics were displayed by the sub-group of five riders who constituted in part, the final Olympic select squad of seven riders.

Finally, in the total groups of riders, there was no significant change in leg power during the racing season (Table III). However, the S group displayed a transient trend towards enhanced leg power in March compared with the NS group, but this trend was reversed with values reduced below pre-season January levels in July.

DISCUSSION

The anthropometric characteristics of the road squad cyclists were typical of highly trained endurance athletes and the somatotype characteristics were representative of similar groups of specifically trained cyclists (Carter, 1978). Differentiating features between select (S) and non-select (NS) members of the squad included height, weight, body fat content and muscularity, all of which favoured the S group, furthermore, it was this group which demonstrated significant body composition changes during the competitive racing season.

Lung function parameters were also typical of highly trained endurance athletes, although there were no changes during the racing season, nor differentiation between S and NS members of the squad. However, the S group displayed a pre-season elevation of haematological indices, although such features were subsequently comparable in both groups, and remained within the normal physiological range of values.

Resting cardiovascular parameters, which were characteristic of endurance trained athletes, showed little change during the racing season, unlike cardiovascular responses to warm-up exercise, which demonstrated characteristic functional economic changes in response to standardised exercise. This was particularly evident in the case of the S group, which displayed a pre-season functional advantage in terms of cardiovascular demand to warm-up exercise.

Personality characteristics showed some divergence from adult norms (Eysenck and Eysenck, 1962) and, in particular, from other road race cyclists (Hagberg, Mullin et al, 1979). This was most evident in the case of the S group at the pre- and early-season assessments, whereby extreme scores on the neuroticism dimension were evident, although such wideranging characteristics were modified by the final mid-season assessment. However, EPI scores may have been affected as much

by small group inter-individual differences as by the vigorous competitive selection procedures employed during the racing season.

During maximal exercise, there were clear trends towards enhanced cardiorespiratory functional capabilities as well as increased absolute and relative power output capacity observed in both the S and NS groups during the racing season. However, it was the S group, in particular, which displayed significant gains in respiratory functional capability specifically, and demonstrated general pre-season superiority over the NS group in terms of cardio-respiratory performance, as well as absolute and relative power output capacity.

The values of VO_2 maximum observed within the S group, which were among the highest recorded in racing cyclists (Hagberg, Mullin et al, 1979), resulted from improvements made during the racing season and were of a similar order of magnitude to those previously reported (Placheta et al, 1973(a), 1973(b)). However, the importance of VO_2 maximum gains should not overshadow the significance of enhanced respiratory efficiency in terms of extended aerobic and anaerobic thresholds during incremental exercise to exhaustion. Indeed, economy of metabolic resources during sustained sub-maximal effort is probably equally important to success in road race cycling as the relatively inefficient utilisation of metabolic energy during brief supramaximal effort.

Finally, leg power, which remained relatively stable and did not differentiate between select and non-select groups, appeared relatively low in comparison with standards based upon other power tests (Margaria et al, 1966; Margaria, 1966). However, this may be explained by the modified vertical jump test utilised, which eliminated the beneficial influence of arms and upper body movement (thus isolating leg action alone), together with the relatively low explosive leg power capability observed in road race cyclists in general (White, J. A. unpublished data).

ACKNOWLEDGEMENTS

The authors would like to thank Mr. J. Hendry, Director of Racing, and the British Cycling Federation National Racing Committee for making the necessary arrangements for cycling squad members to attend the laboratory for testing. The investigation was supported by a grant from the British Cycling Federation, and a detailed technical report submitted to the governing body, in accordance with the agreement undertaken.

REFERENCES

Bonjer, F. H., 1979 "Comparability of the results of the same exercise test carried out in different centres". In: Netherlands Contribution to the International Biological Programme. North Holland Publishing Company, Amsterdam.

- Bonnardeaux, J. L. and Bonneau, J., 1980 "Relationship between blood pressure and work load during a stress test on young men and women". In: "Exercise Physiology". (Landry, F. and Orban, W., Eds.). Symposia Specialists Inc., Miami.
- Burke, E. R., Cerny, F., Costill, D. and Fink, W., 1977 "Characteristics of skeletal muscle in competitive cyclists". *Med.Sci.Sports* 9: 109-112.
- Carter, J. E. L., 1978 "Prediction of outstanding athletic ability — the structural perspective". In: "Exercise Physiology". (Landry, F. and Orban, W., Eds.). Symposia Specialists Inc., Miami.
- Durnin, J. V. G. A. and Womersley, J., 1974 "Body fat assessed from total body density and its estimation from skinfold thickness". *Brit.J.Nutr.* 32: 77-97.
- Eysenck, H. J. and Eysenck, S. B. G., 1962 "Manual for the Eysenck Personality Inventory". Educational and Industrial Testing Service. San Diego.
- Firth, M. S., 1981 "A sports specific training and testing device for racing cyclists". *Ergonomics* 24: 565-571.
- Hagberg, J. M., Mullin, J. P., Barkhe, M. and Linburg, J., 1979 "Physiological profiles and selected psychological characteristics of national class American cyclists". *J.Sports Med.& Phys.Fit.* 19: 341-346.
- Hagberg, J. M., Giese, M. D. and Schnieder, R. B., 1979 "Comparison of three procedures for measuring VO_2 max in competitive cyclists". *Europ.J.Appl.Physiol.* 39: 47-52.
- Heath, B. and Carter, J., 1967 "A modified somatotype method". *Amer.J.Phys.Anthrop.* 27: 54-74.
- Jakeman, P. and Davies, B., 1979 "The characteristics of a low resistance breathing valve designed for the measurement of high aerobic capacity". *Brit.J.Sports Med.* 13: 81-83.
- Margaria, R., 1966 "Assessment of physical activity in oxidative and anaerobic maximal exercise". *Int.Z.Angew.Physiol. Einschl.Arbeitsphysiol.* 22: 115-124.
- Margaria, R., Aghemo, P. and Rovelli, E., 1966 "Measurement of muscular power (anaerobic) in man". *J.Appl.Physiol.* 21: 1662-1664.
- Placheta, Z., Drazil, V., Rous, J. and Novak, A., 1973(a) "Fitness tests based upon submaximal workloads in cyclists". In: "Cycling and Health". (Rous, J., Ed.). Slovak Publishers for Physical Education, Bratislava.
- Placheta, Z., Drazil, V., Rous, J., Kocnar, K. and Matejkova, J., 1973(b) "Sports medical examinations prove helpful in the training preparatory work". In: "Cycling and Health". (Rous, J., Ed.). Slovak Publishers for Physical Education, Bratislava.
- Placheta, Z., 1980 "Youth and physical activity — the development of some functional and morphological indices in 12-15 year old boys with different motor activity". (Placheta, Z., Ed.). J. E. Purkyne University Press, Brno.
- Saltin, B. and Åstrand, P.-O., 1967 "Maximal oxygen uptake in athletes". *J.Appl.Physiol.* 23: 353-358.
- Skinner, J. S. and McLellan, T. H., 1980 "The transition from aerobic to anaerobic metabolism". *Res.Quart.Ex.Sp.* 51: 234-248.
- Stromme, S. B., Ingjer, F. and Meen, H. D., 1977 "Assessment of maximal aerobic power in specifically trained athletes". *J.Appl.Physiol.* 42: 833-837.
- Zuckerman, M. and Lubin, B., 1965 "Manual for the multiple affect adjective check list". Educational and Industrial Testing Service. San Diego.