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A comparative analysis of physiological responses at submaximal work loads between simulated task performances of cycling.

by

Glen Kenny

University of Ottawa

A thesis
presented to the University of Ottawa
in fulfillment of the
thesis requirement for the degree of
Master of Sciences - School of Human Kinetics

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This research is dedicated to the memory of John Slater whose enthusiasm and support inspired me in my work. John was a world champion in ice dancing and held the British National title for many years. He has left behind a legacy of memories not only as a competitor but also as a coach. He was always a champion both off and on the ice. He will be greatly missed.

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Abstract

The purpose of this study was to evaluate the relationships between heart rate (HR), oxygen consumption ($\dot{V}O_2$) and mechanical (Peak crank torque (PCT) and Average crank torque (ACT_{60}) variables in response to submaximal exercise employing a cycling race ergometer (RE), treadmill cycling (TC) and cycling in the field (FC). Eight well trained male cyclists rode at 3 pre-determined submaximal work loads defined in terms of lactate threshold and maximal oxygen consumption ($\dot{V}O_{2max}$). The work intensities identified as sub LT, LT and supra LT were equated on the basis of HR. Voltage signals from the crank arm were recorded as FM signals for subsequent representation of peak crank force (PCT) and average crank torque (ACT_{60}). Field $\dot{V}O_2$ measures were done by Douglas bag procedure while an open circuit method was used for all laboratory testing. Heart rates were recorded with a Polar Electro Sport Tester PE3000. Significant differences ($p<0.05$) in $\dot{V}O_2$ were observed between FC and both laboratory conditions at and below LT intensity. Significant difference ($p<0.05$) was demonstrated in peak crank torque (PCT) between FC and TC at below LT intensity. Significant differences ($p<0.05$) were shown for ACT_{60} between FC and RE at sub LT. No significant differences were demonstrated at Supra LT intensity for $\dot{V}O_2$. Similarly no significant differences were shown for PCT and ACT_{60} for either the LT or supra LT intensities. The observed results of field cycling demonstrated that laboratory conditions would overestimate the oxygen consumption in the field while force measurements suggested that laboratory conditions would underestimate mechanical work expenditures in the field. These differences become reduced at work intensities approximating $\dot{V}O_{2max}$. It was concluded that

HR can not always be used as an indicator of work stress when attempting to equate similar work loads performed under different conditions.

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INTRODUCTION

Heart rate is commonly used as an indirect measure of energy expenditure in the field. Similarly, target HR's determined by laboratory testing are commonly utilized to identify training intesities, such as above or below the lactate threshold, for the athlete in the field. Whichever of the above purposes HR collection may serve, the methodology associated with its use assumes that the relation between HR and $\dot{V}O_2$ remains constant under all conditions.

It has been established that a reasonably linear relationship exists between HR and VO_2, particularly at moderate levels of exercise (Booyens and Harvey, 1960; Pugh, 1974; Kovac et al., 1975; Christensen et al., 1983; Washburn and Montoye, 1985; Astrand and Rodhal, 1986). However, it has also been shown that the consistency and reliability of the relationship may be influenced by a number of variables such as the size of working muscle groups (Bevegaard et al., 1966; Kovac et al., 1975), the magnitude of the static work component (Kiblom and Persson, 1981; Nielsen and Meyer, 1987; Maas et al., 1989) whether or not the work is performed in a steady or non-steady state (Fernandez et al., 1974) fluctuations in ambient temperature (Leblanc, 1957; Brown et al., 1985); the degree to which other sources of stress are present inside and outside of the laboratory (Astrand and Rodhal, 1986). There has been some research which has demonstrated that, so long as the testing mode is identical with the athletes specific sport activity or work performance requirement, the above factors and their effect on performance variables may be minimized (diPrampero et al., 1971, Stromme et al., 1977; Wilmore, 1984 and deBoer et al., 1986). In particular, responses to cycling have been assessed on various cycling ergometer devices such as the 'Monark Ergometer' which according to the principles described by Wilmore (1984), simulate the actual outdoor cycling. There is however evidence to indicate that simulation based solely on mechanical action may not be a sufficient criteria for ensuring similarity in physiological response. For example, it has been shown that, in order for laboratory measurements to be representative of field, components such as pedalling frequency (Gaesser and Brooks, 1975; Hagberg et al., 1981; Faria et al., 1982) seat height (Laurence Shernun and deVries, 1976; Nordeen-Snyder, 1977), crank length (Carmichael et al., 1982; Conrad and Thomas, 1983), posture (Faria et al, 1978), toe clips (Davis and Hull, 1981; Ribisl et al., 1982; Brodowicz et al., 1982, Moffat and Sparling, 1985) must be identified and the same conditions reproduced in the laboratory. Moreover, most studies of this nature also identify the problem of equating for conditions of rolling and wind resistance, thermal and humidity characteristics and the metabolic costs associated with maintaining balance or overcoming inertial characteristics of different apparatus, most of which cannot be duplicated in the laboratory. Thus it would seem that the best approach for establishing training intensities for cyclists would be to conduct progressive work tests in the field.

Verification of the degree to which field and laboratory measurements are comparable might be accomplished by direct assessment of oxygen consumption in the field. However the various field methods of metabolic cost available to date are not without serious limitations. The conventional Douglas bag and the Krofranyi-Michaelis gas meter methods impose a weight or resistance penalty and are laborious, time consuming and are restricted to single load situations (Louhevaara and Imarinov, 1985; Astrand and Rodhal, 1986). The application of such portable devices as the Oxylog (P.K. Morgan Ltd, Chatham, Kent) is both costly and limited by a relatively low maximum $\dot{V}O_2$ of about 3.00 $L{\cdot}min^{-1}$ (Harrison et al., 1982). Therefore, the only option available for developing controlled intensity training programs for athletes which are based on their individual physiological performance characteristics is to equate the mechanical conditions as much as possible and utilize laboratory measurements of HR and $\dot{V}O_2$ assuming that, even if mechanical loading may differ from field to laboratory, the HR-$\dot{V}O_2$ relationship will remain the same. However, there are few data in the literature with which to justify this assumption.

The purpose of this study was to evaluate cardiovascular (HR), metabolic ($\dot{V}O_2$ and mechanical (PCT and ACT_{60}) variables for differences in response to submaximal exercise employing a modified cycle ergometer (RE) and during free cycling on a treadmill (TC) in the laboratory and while cycling in the field (FC) in order to investigate the feasibility of applying laboratory measurements to control field performances.

METHODOLOGY

Subjects

Eight well trained male cyclists participated in the study (table 1). The subjects were informed of the experimental procedure prior to signing consent forms (appendix R).

Table 1: Subject Data

	RANGE	MEAN	Std. Dev.
AGE (YEARS)	20 - 30	22.9	3.6
WEIGHT (KG)	62 - 85	74.9	7.9
HEIGHT (cm)	168.5 - 186	179.4	6.1

Procedures

Testing required 4 laboratory sessions and one field session. The first two sessions were required to determine the subjects maximal oxygen uptake ($\dot{V}O_{2max}$) on each of the two separate tasks: treadmill cycling (TC) and race ergometer cycling (RE). The information was subsequently used to establish the workload intensities for the subject's following work sets. The remaining three testing periods were used to evaluate submaximal work response both in the field and laboratory settings.

The procedure to determine each subjects $\dot{V}O_{2max}$ followed a continuous progressive work test protocol for two cycling tasks (RE and TC). The treadmill cycling test was performed on a standard racing bike at a cadence chosen by the subject during pilot tests and progressed by increasing grade by 0.5% increments at 1 minute intervals from an initial grade of 2%. Treadmill velocity was maintained at 20 mph during the test until maximum $\dot{V}O_2$ was achieved. The race ergometer $\dot{V}O_2$ maximum test required the subject to pedal at the same cadence and at an initial load equivalent to that calculated for the treadmill (based on the weight of the subject) (appendix G) and increased by work increments similar to those of the treadmill test at the end of each 1 minute work period.

Micro samples of finger-tip blood were taken at the end of each workload during the race-ergometer max test and used in conjunction with Ventilation, $\dot{V}O_2$, $\dot{V}CO_2$ and Ventilatory equivalents for O_2 and CO_2 ($\dot{V}/\dot{V}O_2$, $\dot{V}/\dot{V}CO_2$) to establish three submaximal exercise loads for subsequent evaluation in the field (appendix P). Capillary blood for determination of blood lactate concentration has been shown to give similar results to those seen in arterial blood (Laughlin et al., 1964; Langlands et al., 1965). Determinations of arterialized venous pH, pCO_2 and lactate values have been demonstrated to be similar to those measured in arterial samples (Forster et al., 1972). In contrast venous sampling has not been considered to be suitable for anaerobic threshold (AT) determination (Yoshida et al., 1982; Yeh et al., 1983). The technique of capillary sampling as used in this study, in conjunction with non-invasive methods for AT determination, provide a sufficient indicator for threshold determination. Lactate threshold determinations were used to arrive at categories of work for the competitive cyclist that would be representative of their training and competitive circumstances. This approach was not used to equate working loads between field and laboratory conditions but rather to assure that work intensities would be significantly different for each treatment while at the same time approximating the exercise intensities that would be experienced during training and competition. Blood samples for lactate analysis were also taken following each steady state exercise load for all conditions at 1 minute and 3 minute post exercise.

The submaximal work loads in the field required the subject to ride a specially equipped race bike in the field at three work intensities which approximated LT-10%$\dot{V}O_2$, LT and LT+10%$\dot{V}O_2$. The work intensities were equated on the basis of a target HR established during the laboratory test. Each work load was performed at a constant work rate for a 10 minute interval. The cyclists were asked to modify their gear combination to achieve the target HR while maintaining the same cadence (monitored by a cyclometer) which had been used during the $\dot{V}O_2$ max tests.

The submaximal laboratory tests required the subjects to perform three constant work intensities on the two tasks (RE and TC) at similar target HR's used in the field. The subjects were required to cycle at a constant rate for a period of 10 minutes. Pedal frequencies and gear ratios on the treadmill were similar to those used in the field. Pedal frequency on the RE was the same as the field and the resistance was adjusted in the first minutes of the test to achieve the desired target HR's.

Equipment

All treadmill cycling tests were performed on a Quinton treadmill equipped with a rubberized surface with maximum speed capability of 25 mph and maximum gradient change of 40 degrees. The racing bike used for FC and TC conditions was a Grandis Italian racing bike equipped with adjustable Dura-Ace handle bars and Look lock pedals. The seat was adjustable both vertically and horizontally.

The race bike ergometer combined a mounted racing bike (Bridgestone) where the chain ring was directly connected by a standard bicycle chain to the front wheel ring gear of a Monark ergometer making it possible to use the braking load system of the Monark Ergometer. Both the mounted racing bike and Monark ergometer were braced within a metal frame which allowed the bike to act as a single system. The handle bar and seat were both adjustable similar to measurements which approximated those of the racing bike and equipped with Look lock-in pedals.

A specially build transferable crank which incorporated strain gauges was installed to measure the force acting on the crank arm and was used for all cycling conditions. The strain gauges were located on both the anterior and posterior sides of the crank arm (85 mm from the axel origin). Only the forces normal to the crank axis in the plane of crank longitudinal axis were recorded. Values recorded from the strain gauges were used to describe relative differences among the three conditions rather than to represent absolute force or work production.

Heart rate was recorded by means of a wireless transmission device (Polar Electro PE3000). Oxygen consumption ($\dot{V}O_2$) was determined by open circuit gas analysis during the laboratory tests. The open circuit employed an Amtek S-3A Oxygen Analyzer and an Amtek CD-3A Carbon Dioxide Analyzer for O_2 and CO_2 analysis and a Morgan Ventilometer Mark 2 incorporated into a metabolic cart for repeated $\dot{V}O_2$. Field $\dot{V}O2$ was measured by Douglas bag technique in which a sample was retained for volumetric and concentration analysis. A volumetric reader (Cowan Parkinson Measurement) was used to measure the volume of expired gases collected for the 30 sec collection period and gas samples were collected in a mylar balloon bag for analysis of O_2 and CO_2 volumes.

Analysis

Table A shows the one factor experimental model with repeated measurements used in this study. The rows represent individuals (subjects) and the columns represent modes of cycling in which the model is presumed to represent a random sample of individuals tested under three different treatment conditions of cycling. One basis of classification, the columns, is fixed. The other basis of classification, the rows, is random. This model was used to assess the variables ($\dot{V}O_2$, HR, PCT, ACT$_{60}$ and lactate) for each of the respective intensities seperately and to assess condition effect in order to identify any similarities and/or dissimilarities between field and laboratory cycling (Ferguson, 1976). The General Linear Model (GLM) procedure for computer analysis was used compute the data. In order to deal efficiently with the correlation of repeated measures, the GLM process used the multivariate method of specifying the model even if a univariate analysis is required (SAS Institute Inc., 1985; Freund et al., 1986).

TABLE A. STATISTICAL ANALYSIS MODEL

		TREATMENT CONDITION		
	SUBJECT	FIELD CYCLING	RACE ERGOMETER	TREADMILL CYCLING
SUB IACTATE INTENSITY	1	41.3	46.1	49.5
	2	36.3	42.0	41.2
	3	52.5	55.5	49.9
	4	38.1	45.4	51.1
	5	30.7	48.0	47.2
	6	29.8	48.7	50.4
	7	39.3	45.5	47.8
	8	46.3	47.4	47.9

** Values for oxygen consumption at SubLT*

RESULTS

PHYSIOLOGICAL RESPONSES

Heart Rate.

The heart rates across conditions were not significantly different ($p<0.05$). This demonstrated that the attempt at equating relative exercise intensity by controlling HR during different modes of exercise, including field cycling, was successful and that the experimental conditions had been met (table 2). The difference in HR across the 3 work intensities demonstrates that the values chosen were significantly different to ensure a large enough intensity or work stress difference. Based on the RE max test the % of max HR for each intensity was equivalent to 83.7% at sub LT, 89% at LT and 93% at supra LT.

Table 2: Mean Heart Rate Values (bpm)

	INTENSITY		
CONDITIONS	**SUB LT**	**LT**	**SUPRA LT**
FIELD CYCLING	157.6	168.4	176.1
RACE ERGOMETER	157.6	168.1	175.5
TREADMILL CYCLING	156.9	168.1	175.1

***** *Denotes significant difference with field cycling at $p < 0.05$*

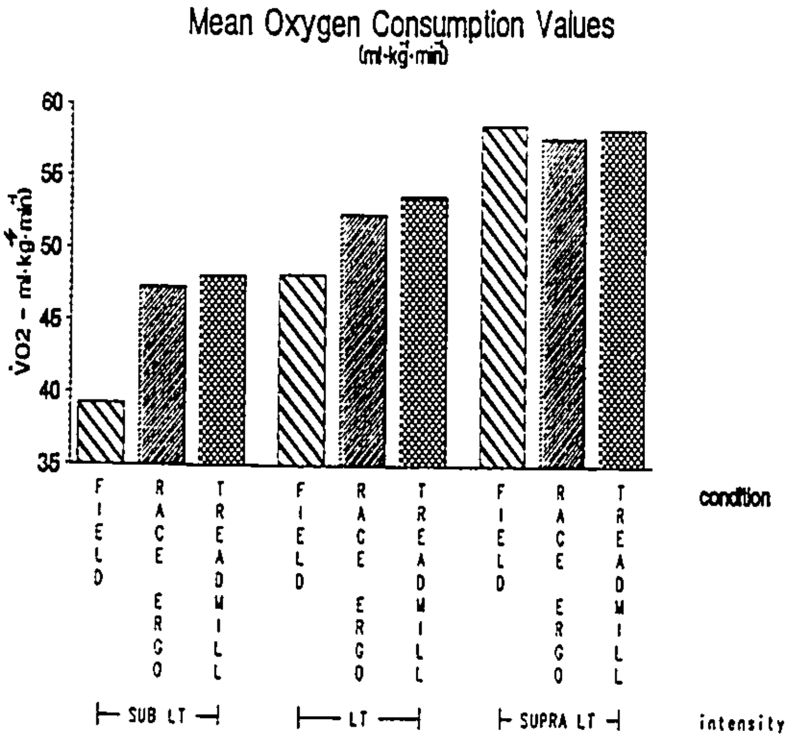

Figure 1: Mean Oxygen Consumption Values.

Oxygen Consumption.

Oxygen consumption was significantly lower in the field compared to both laboratory conditions at subLT and LT intensities (table 3). This difference from field $\dot{V}O_2$ at the subLT intensity of RE and TC was equal to 19.0% and 21.8% respectively. At the LT intensity this variation was equivalent to 10.8% and 13.1% for RE and TC respectively. This difference dissappeared completely at supraLT approaching $\dot{V}O_{2}max$ (figure 1). The lower observed field values were observed for all 8 subjects at subLT with respect to FC and RE and 7 of the 8 subjects between FC and TC. At the LT 6 of the 8 subjects demonstrated lower values (Appendix L). The standard deviation for the three conditions demonstrated that outdoor cycling was exerting a substantial influence on the variation of performance as well as demonstrating an influence on the level of performance. This effect was evident for the 3 work intensities.

Table 3: Mean Oxygen Consumption Values ($ml \cdot Kg^{-1} \cdot min^{-1}$)

	INTENSITY		
CONDITION	**SUB LT**	**LT**	**SUPRA LT**
FIELD CYCLING	38.3	47.0	58.6
Std dev	7.6	5.5	6.4
% MAP	63	77	94
RACE ERGOMETER	47.3*	52.7*	57.5
Std dev	3.9	5.5	2.5
%MAP	75	84	92
TREADMILL CYCLING	49.0*	54.1*	58.2
Std dev	3.1	2.5	1.8
%MAP	77	86	93

** Denotes significant difference with field cycling at $p < 0.05$*

Average crank torqe (ACT_{60}) and peak crank torque (PCT).

Peak crank torque during field cycling was significantly higher than treadmill cycling at the subLT intensity and showed a non-significant trend to be higher than both laboratory conditions at all intensities (table 5 and figure 3). Average crank torque values (ACT_{60}) in the field were similar to PCT in showing higher values than both laboratory conditions. However ACT_{60} was different from PCT in that the values remained similar rather than increasing with increasing intensity (table 4).

ACT_{60} in the field did show a significant differences compared to RE at the subLT intensity (figure 2). The standard deviations for both PCT and ACT_{60} showed that the outdoor cycling had a substantial influence on the variation in performance although its influence on the mean level of performance was negligible.

Table 4: Average Crank Torque (N·s)

	INTENSITY		
CONDITIONS	**SUB LT**	**LT**	**SUPRA LT**
FIELD CYCLING	176	171	176
Std dev	52	46	42
RACE ERGOMETER	150*	157	166
Std dev	29	22	15
TREADMILL CYCLING	159	162	173
Std dev	14	23	7

** Denotes significant difference with field cycling at $p < 0.05$*

Table 5: Mean Peak Crank Torque Values (N)

	INTENSITY		
CONDITIONS	**SUB LT**	**LT**	**SUPRA LT**
FIELD CYCLING	417	413	446
Std dev	118	89	95
RACE ERGOMETER	383	403	432
Std dev	54	42	57
TREADMILL CYCLING	378*	390	427
Std dev	30	67	28

** Denotes significant difference with field cycling at $p < 0.05$*

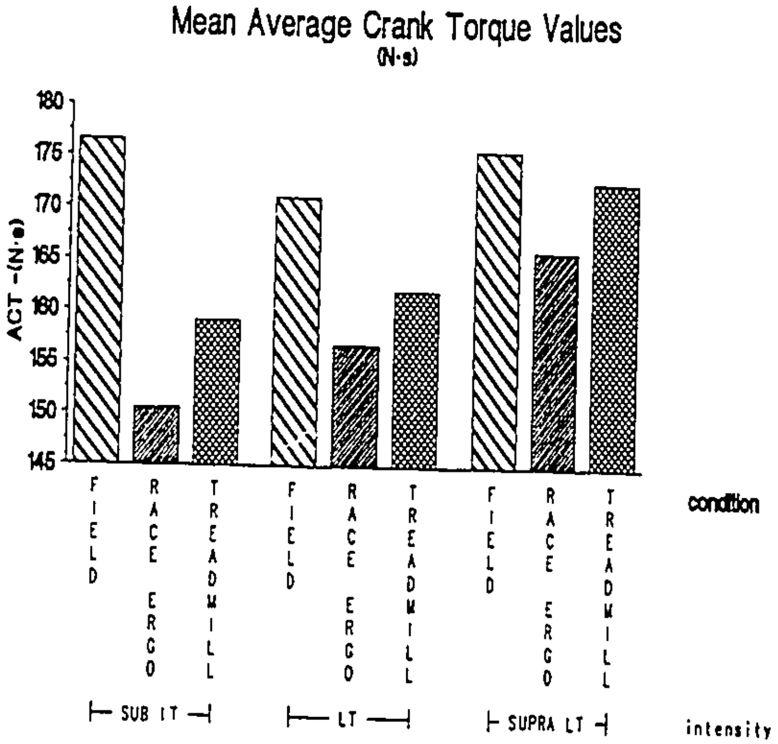

Figure 2: Mean Average Crank Torque Values. A comparison of crank torque for a 1 minute sample period.

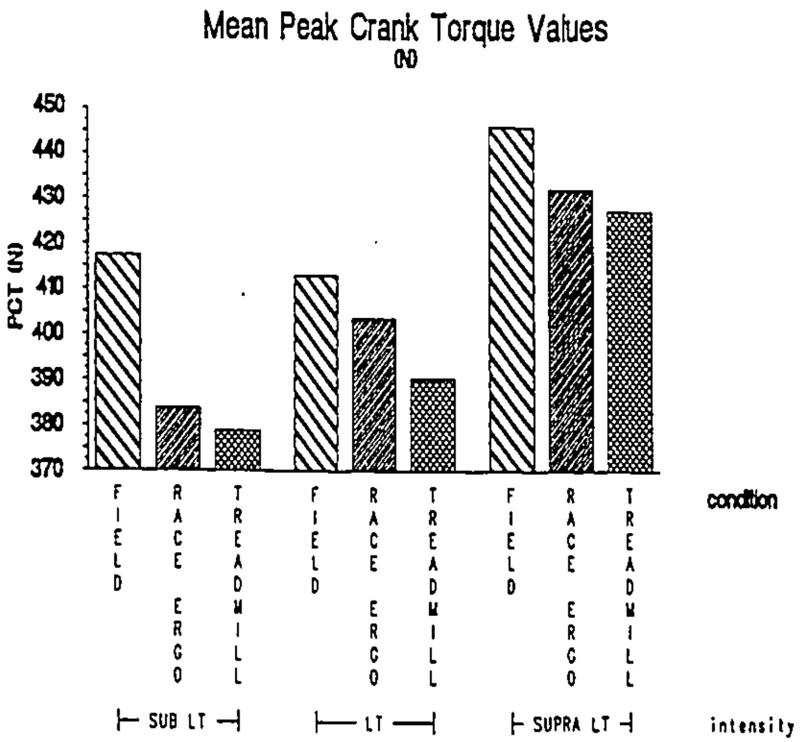

Figure 3: Mean Peak Torque Values. A comparison of peak torque for a 1 minute sample period.

Performance indices

PCT/$\dot{V}O_2$ and ACT/$\dot{V}O_2$.

The relationship between oxygen consumption and both PCT and ACT show that the torque for a given level of oxygen consumption was significantly higher in the field than either laboratory condition at the subLT intensity with a similar trend at LT (where significance was achieved only between FC and RE at this intensity) (table 6). This trend almost completely dissappeared at the supraLT intensity (figure 4 and 5).

Table 6: Mean Index Values

		INTENSITY		
CONDITIONS	**INDEX**	**SUB LT**	**LT**	**SUPRA LT**
FIELD CYCLING	PCT/V̇O2	11.2	8.7	7.7
	ACT60/V̇O2	4.8	3.7	3.1
	PCT/HR	2.7	2.5	2.6
	ACT60/HR	1.1	1.1	1.0
RACE ERGOMETER	PCT /V̇O2	8.2*	7.8	7.6
	ACT60/V̇O2	3.2*	3.0*	2.9
	PCT/HR	2.4*	2.4	2.4
	ACT60/HR	0.9*	0.9	0.9
TREADMILL CYCLING	PCT/V̇O2	8.0*	7.3	7.4
	ACT60/V̇O2	3.6*	3.1	3.0
	PCT/HR	2.4*	2.3	2.4
	ACT60/HR	1.0*	0.9	1.0

** Denotes significant difference with field cycling at* $p < 0.05$

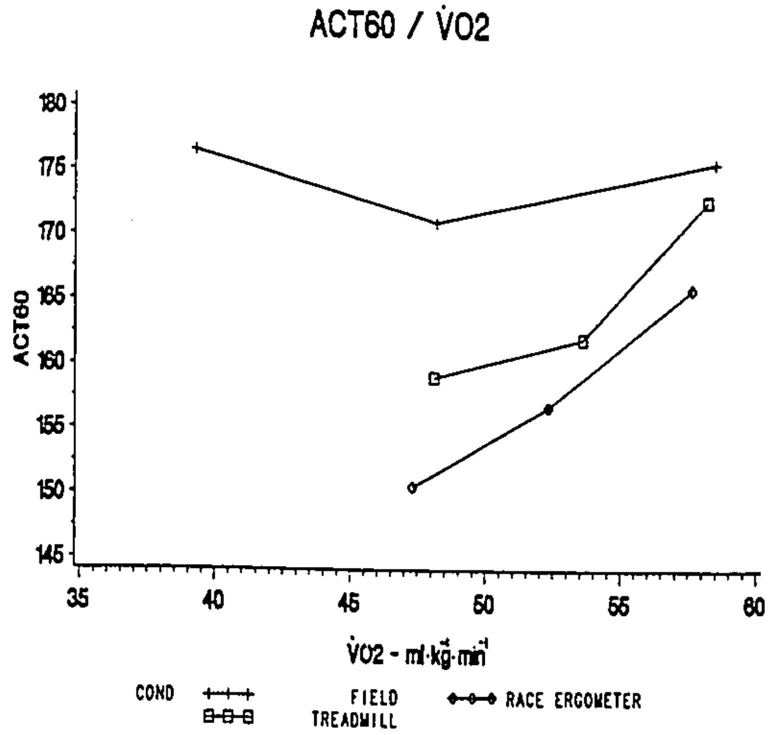

Figure 4: Average Crank Torque/V̇O_2 relation.. A look at the mechanical and metabolic relationship.

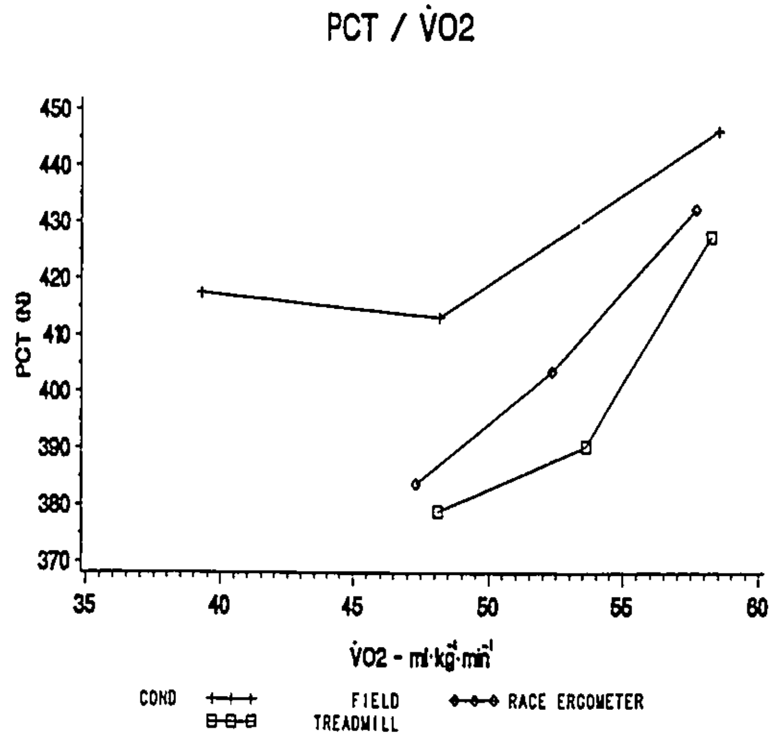

Figure 5: Peak Crank Torque/$\dot{V}O_2$ relation. A look at the mechanical and metabolic relationship.

$\dot{V}O_2$ as a function of HR - oxygen pulse.

The oxygen pulse (ie. $\dot{V}O_2$ per unit of HR) was significantly lower in the field compared to both laboratory conditions at the subLT and LT intensities. This difference dissappeared completely at the supraLT intensity approaching $\dot{V}O_{2max}$. In effect these curves (figure 6) and the performance index curves, ($ACT_{60}/\dot{V}O_2$ and $PCT/\dot{V}O_2$) (figure 4 and 5) demonstrate a significant difference in slope between field and laboratory conditions.

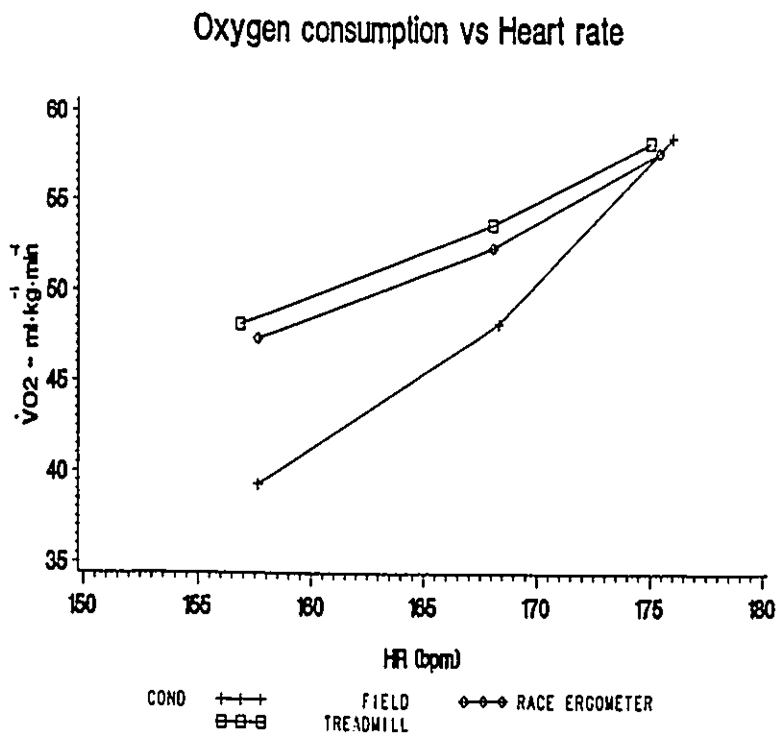

Figure 6: Oxypulse Curve. An overview of the relationship between metabolic (V̇O2) and cardiovascular (HR) variables.

Table 7: Oxygen Consumption Differences (ml·Kg^{-1}·min^{-1})

	CONDITION		
INTENSITY	**FIELD CYCLING**	**RACE ERGOMETER**	**TREADMILL CYCLING**
LT-sub LT	9.0	5.0*	5.5*
Std dev	4.6	3.1	3.5
supra LT-LT	10.3	5.3*	4.6*
Std dev	3.4	2.8	2.4

* *Denotes significant difference between field cycling $p<0.05$*

PCT/HR and ACT_{60}/HR against $\dot{V}O_2$.

Comparisons of PCT/HR and ACT_{60}/HR to oxygen consumption were done to reflect the oxygen cost of similar work (PCT and ACT_{60}) and exercise stress (HR) conditions and are therefore rudimentary demonstrations of either work efficiency and or similarity or disimilarity in exercise mode. If efficiency is identical across all conditions or the exercise mode is identical across all conditions it would be expected that the relationship of the index PCT and ACT_{60}/HR to $\dot{V}O_2$ would be identical at each intensity. Figures 7 and 8 show significant differences between field and laboratory conditions at subLT and a similar trend at the LT intensity and supraLT intensity.

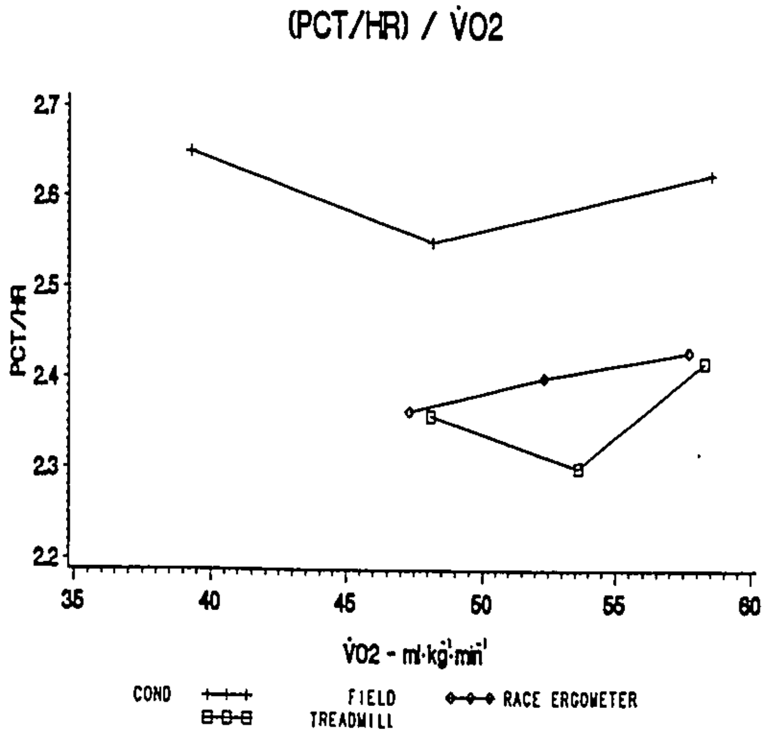

Figure 7: PCT/HR / $\dot{V}O_2$ relationship.

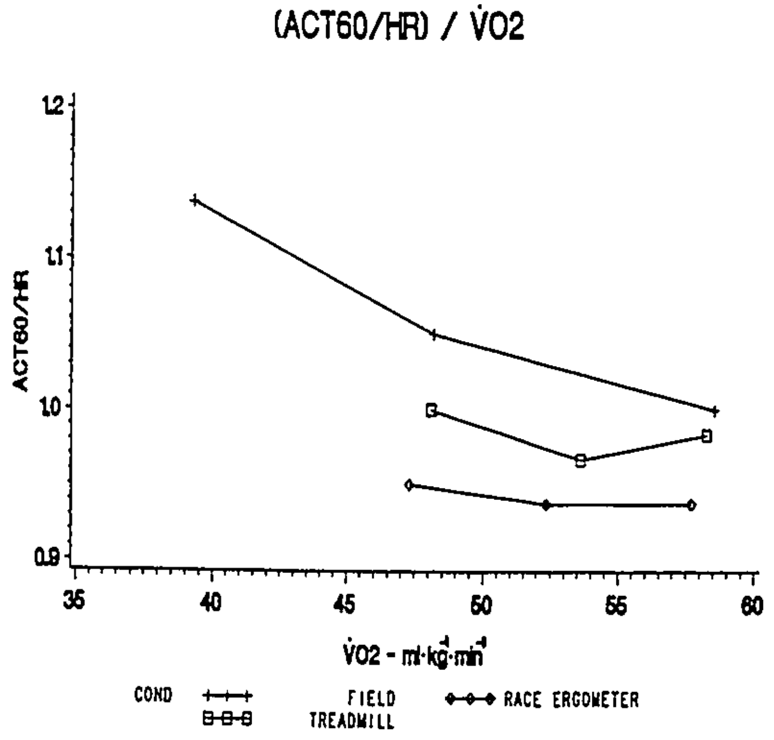

Figure 8: ACT_{60}/HR / $\dot{V}O_2$ relationship.

Performance Correlations.

The ACT_{60}/HR against $ACT_{60}/\dot{V}O_2$ and PCT/HR against PCT/$\dot{V}O_2$ correlations (Table 8) show that in particular for subLT and LT the change in average crank torque and/or peak force for a given HR between laboratory and field seems to compensate for the difference in $\dot{V}O_2$ in the laboratory and field as shown by the fact that these indices when correlated show a moderate relationship whether this is physiologically significant or not is difficult to say on the basis of the data. However it is evident from the field correlations that the work efficiency (mechanical efficiency) remains constant with increasing work intensity as seen by the strong correlations in contrast to the less consistent and moderate correlations demonstrated in both laboratory cycling tasks.

Table 8: Pearson Correlations

		CONDITIONS		
INTENSITY		**FIELD**	**RACE ERGOMETER**	**TREADMILL**
		PCT/HR	**PCT/HR**	**PCT/HR**
SUB LT	**PCT/$\dot{V}$O2**	0.94	0.99	0.50
LT	**PCT/$\dot{V}$O2**	0.86	0.60	0.92
SUPRA LT	**PCT/$\dot{V}$02**	0.81	0.83	0.35

		CONDITIONS		
INTENSITY		**FIELD**	**RACE ERGOMETER**	**TREADMILL**
		ACT60/HR	**ACT60/HR**	**ACT60/HR**
SUB LT	**ACT60/$\dot{V}$02**	0.96	0.99	0.63
LT	**ACT60/$\dot{V}$O2**	0.91	0.64	0.88
SUPRA LT	**ACT60/$\dot{V}$O2**	0.91	0.60	0.33

Blood lactic acid.

Analysis of the 1 min post blood exercise lactic acid value revealed a significant difference ($p<0.05$) between FC and RE at LT (figure 9). The 3 min post exercise blood lactic acid values demonstrated no significant difference across conditions ($p<0.05$) (figure 10). Both the 1 min and 3 min FC values showed a tendency to be lower than those of laboratory cycling task (table 9).

Table 9: Mean Blood Lactate Values (mM)

		INTENSITY		
CONDITIONS	TIME (min)	SUB LT	LT	SUPRA LT
FIELD CYCLING.	1.0 3.0	3.84 3.51	4.36 4.21	6.86 5.94
RACE ERGOMETER	1.0 3.0	4.30 3.57	5.83* 4.80	7.44 6.50
TREADMILL CYCLING	1.0 3.0	4.72 3.60	5.47 3.99	7.58 6.24

***** Denotes significant difference with field cycling at $p < 0.05$***

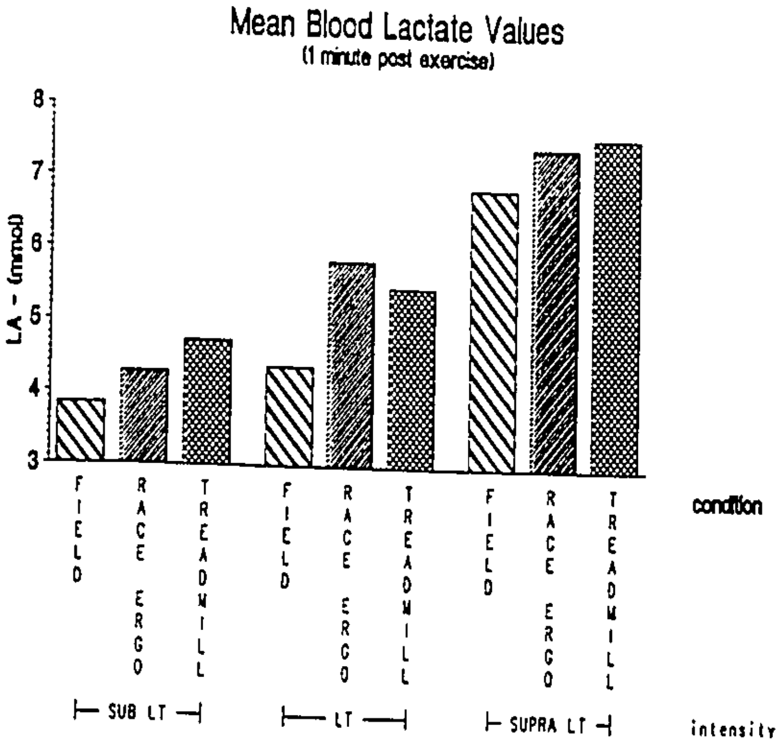

Figure 9: Mean Blood Lactate Values. Values for 1 minute post exercise.

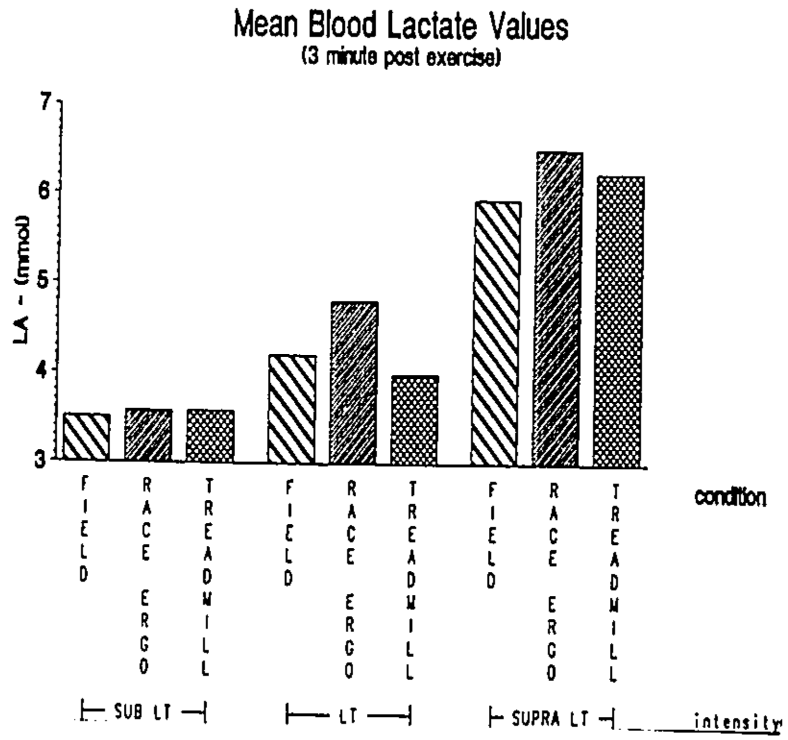

Figure 10: Mean Blood Lactate Values. Values for 3 min post exercise.

DISCUSSION

The technique of equating work stress under the three conditions of field cycling (FC), treadmill cycling (TC) and race ergometer cycling (RE) by adjusting work load to a target heart rate proved to be quite workable as average heart rates at each intensity varied by less than 1 bpm across each condition. The experimental protocol required that a given subject be at the same relative level of exercise stress for 3 submaximal work intensities in each exercise mode (1 field and 2 laboratory conditions). The observation of virtually identical HR in each exercise mode at subLT intensity and again at LT and SupraLT intensities verified that it was possible to achieve identical exercise stress on the basis of a target HR. Thus by utilizing the same pedalling frequency on the treadmill and race ergometer as had been utilized in FC, in order to produce HR's which had been pre-determined in progressive maximal aerobic testing to be subLT, LT and supraLT, it was possible to adjust treadmill gradient (with constant speed) or flywheel resistance on the ergometer to bring the subjects to the same level of exercise stress in the laboratory as had been demonstrated in the field by progressively increasing work rate until HR plateaued at the target level.

Oxygen consumption and HR relationships are normally expected to conform to a linear function across work intensities below maximal aerobic performance levels. The slope of this curve remains stable for similar exercise modes. Thus it was expected that the HR to oxygen consumption relationship (oxypulse) would be quite similar for bicycle and treadmill exercise in the laboratory and this was verified by the results (figure 6). This similarity in response is normally expected to be demonstrated between field cycling and both laboratory cycling tasks. The simulation of field performances in laboratory testing is assumed to represent the demand and time-course response of field work where the task utilizes the same large muscle groups and mechanical attributes identified in the field (Astrand and Rodhal, 1976; Wilmore, 1984). This was not verified by the results. The results of the study identified that field cycling showed significantly lower $\dot{V}O_2$ at both subLT and LT intensities, with a loss of this trend near maximal intensity. Significant changes in exercise mode such as would be demonstrated with the performances of a given level of work by distinctly different volumes of muscle mass (ie. as in the performance of the same workload with arm and leg musculature) (Kovac et al., 1974, Astrand and Rodhal, 1976) results in different slopes to the linear HR/$\dot{V}O_2$ relationship. The significant variation in $\dot{V}O_2$ per unit HR identified in this study indicates that the differences may possibly be the result of a change in work efficiency (mechanical efficiency) or simply that the work performed in the field and laboratory are quite distinct exercise conditions.

Modifications in equipment as in the use of toe clips (Brodowicz et al., 1982), crank arm length (Carmichael et al., 1982), seat height (Laurence Shennum and deVries, 1976; Nordeen-Snyder, 1977) and handle bar position (Faria et al., 1978) have been shown to affect cycling efficiency or lead to reductions in oxygen consumption. Similar studies have shown that pedalling rate has an effect on submaximal responses of competitive cyclists with an increase in energy expenditure observed when pedalling slower or faster than "most efficient" (Seabury et al., 1976; Hagberg et al., 1981). The variation observed for $\dot{V}O_2$ in this study is not a result of changes in equipment or cycling cadence variations. The test protocol performed in this study was designed to be sensitive to such expected variations determined by previous researchers. The same bike and equipment was utilized for both field and treadmill cycling. However the important analogy that can be drawn from the results of previous work, is a similar degree of sensitivity in the physiological response which has been observed with changes in equipment. However the change observed in this study is demonstrated as a reduction in oxygen consumption resulting from a change in the condition or environment where the task is performed.

The significant differences in the oxygen consumption and the higher trends observed with both mechanical parameters (PCT and ACT_{60}) suggest a greater efficiency in field cycling as opposed to laboratory cycling when PCT and ACT_{60} are plotted against $\dot{V}O_2$ (Figure 4 and 5). The figures do identify a greater pedal stroke efficiency with a lower $\dot{V}O_2$ per unit force applied in the field as compared to that same task performed in the laboratory. However, reference to the curves of PCT/HR and ACT/HR plotted against $\dot{V}O_2$ (Figure 7 and 8) shows a reasonable maintenance of work per unit of exercise stress relationship during FC and during each laboratory cycling condition, even though $\dot{V}O_2$ is significantly less at the subLT and shows a trend to be less at the LT condition in the field than in the laboratory. If the field condition were truly more efficient it would be expected that the exercise stress (ie. HR) would be less for a given level of work performance (ie. ACT_{60} and PCT) and therefore demonstrate the same lower values in the field as has been shown by $\dot{V}O_2$.

These results do not rule out the possibility that changes in mechanical efficiency could be accounted for by some of the variation in $\dot{V}O_2$ demonstrated at subLT and LT workloads, with the greatest variation seen at subLT equivalent to 21.8%. The results do emphasize that the difference must be to a large degree attributed to a change in mechanical function (as opposed to a change in cycling efficiency). Figure 6 demonstrates that both laboratory cycling tasks impose a greater oxygen cost than the field but the reverse trends of higher mechanical work performed in the field as demonstrated in the mechanical variables - PCT and ACT_{60} (Figure 2 and 3) are also quite distinct. Unlike either laboratory cycling task, field cycling did not show a stepwise increase in force output as might be expected with an incremental increase in work. Field cycling demonstrated a trend towards higher mechanical work and one which changed insignificantly with successive increases in workload. Although crank torque values in the field were higher throughout, the mean blood lactate values for field cycling did not demonstrate a trend similar to that of the higher crank torque values but instead showed lower values when compared to either laboratory cycling task (Figure 8 and 9). Furthermore, the energy cost in the field, as measured by $\dot{V}O_2$, demonstrated a greater increase per unit increase in HR. Table 6 reveals the magnitude of increase in the relative oxygen consumption between workload increments in the field to be almost double the increase in $\dot{V}O_2$ per unit increase in HR identified for race ergometer cycling or treadmill cycling. Such a variation in the magnitude of increase in $\dot{V}O_2$ would not have been expected considering the similarity in the task sturcture and performance requirement of each laboratory task, especially between field and treadmill cycling.

The basic principles of task specificity described by Wilmore (1984) states that so long as the basic testing mode is identical with the athletes specific sport activity, the data obtained will be representative of the performances in the field. This basic criterium was observed in both laboratory cycling tasks but clearly was not supported by field and laboratory cycling comparisons. Application of the principle of task specificity to field cycling would have implied that the responses identified in the laboratory should have been equal to those observed in the field. This would presumably be the case if the conditions were equally matched in terms of the skill level required. The results support the contention that field cycling and laboratory cycling are different tasks. As stated earlier, the time-course and slope of both metabolic ($\dot{V}O_2$) and cardiovascular (HR) responses each reveal a unique response which one might associate with different muscular activity patterns (Kovac et al., 1974;

Astrand and Rodhal, 1976). The HR/$\dot{V}O_2$ relationship shows a higher correlation when compared to well practised tasks than when compared to novel tasks and this higher correlation is also expected to persist with increases in work intensity (Washburn and Montoye, 1985). It is plausible that both forms of laboratory cycling are really 'novel' tasks compared to field cycling, especially at the lower work intensities where overall efficiency differences may account for some of the variation observed between field cycling and laboratory cycling.

Other considerations can be identified within the mechanics of the sport itself. The fraction of power spent against non-aerodynamic forces is very large (90% or greater) in walking and running, intermediate in speed skating, and rather minor (10% or less) in cycling (Di Prampero, 1986). The following factors underly the non-aerodynamic energy expenditure:

(1) potential and kinetic energy changes due to the oscillation of the center of mass of the body in the vertical plane and to its acceleration (deceleration) at each stride (in walking, running and skating).

(2) friction of the skate blade or of the wheel with the terrain (in skating and cycling).

(3) internal work or work not leading directly to changes of position of the center of mass of the body (ie. stabilizing contractions or activation energy)

(4) muscular contraction for the maintenance of posture.

(5) the work of the respiratory muscles and of the heart.

In cycling, the saddle which supports and stabilizes the body reduces the energy waste against non-aerodynamic forces. The mechanical arrangement allows employment of very nearly all of the subjects metabolic power against air resistance

(DiPrampero 1986). By introducing the cycling task to a different set of work conditions it might be postulated that the non-aerodynamic forces differ enough to result in changes in stroke mechanics and therefore in the physiological observations of this study. The difference may be seen in the internal work component (Wells et al. 1986). The inclusion of the internal work rate component in estimating the power developed by the subjects would result in a rather dramatic change in the relationship between HR and work intensity. Thus, the differences between conditions as seen in these data may be explained as a change in the net work of eccentric and concentric contraction during the pedalling stroke resulting from changes in work conditions.

Similar results have not been directly documented in previous work dealing with sport activities. However, Christensen et al., (1983) and Astrand and Rodhal (1986) observed the same trend of difficulty in transposing estimates of metabolic cost through the use of HR/$\dot{V}O_2$ relationship established with dissimilar tasks. Their results show that the technique of estimation based on the HR/$\dot{V}O_2$ relation was poor when used for ordinary daily activities. While their observations were on non-athletic performances and therefore are not directly comparable to the characteristics of this study, it is nevertheless noteworthy that they observed the same trend of difficulty in transposing estimates of metabolic cost.

A precise accountability of the observed differences in both $\dot{V}O_2$ and ACT_{60} and PCT is not possible with the information of this study. However the fact that such a large variation equivalent to 19% and 21.8% (RE and TC respectively) at the subLT intensity is very significant when it is considered that all 8 of the subjects demonstrated lower $\dot{V}O_2$ in the field and that 6 of the 8 subjects showed lower values at the LT intensity equivalent to 10.8% and 13.1% (RE and TC respectively) (Appendix L).

Differences in ambient temperature might be thought to be a partial contributor to the observed variations between field and laboratory values, where large fluctuations in field temperatures were recorded from subject to subject (appendix O). However the field temperatures were both higher and lower on different occassions than laboratory temperatures and yet all 8 subjects consistently showed lower $\dot{V}O_2$ values in the field. In addition, if thermal or humidity conditions were indeed a primary explanation we would have expected to see the difference to be demonstrated at the higher intensities where the effect would be expected to be more pronounced but this was not the case. Therefore it seems that the difference in energy cost must be predominantly explained by changes in the skill level requirement of the tasks. In other words, field cycling and laboratory cycling tasks were each distinct exercise tasks leading to the speculation that the energy requirements may well have varied because the demand of each of the two conditions changed significantly at the lower workloads. Unfortunately, these data only allow one to guess that the differences in balance, maintenance and inertial characteristics on the laboratory apparatus may have had a significant effect on the cycling mechanics therefore altering the metabolic cost sufficiently to result in the observed variations in HR/$\dot{V}O_2$ between field and laboratory.

Perhaps the most important observation is that this study has demonstrated the difficulty associated with transposing energy cost based on laboratory testing using similar work mechanics. The use of HR monitoring to establish target work intensities during field training at workloads at LT or below may be significantly misrepresented. These data on field cycling have demonstrated that laboratory conditions would overestimate the oxygen consumption in the field while force measurements have suggested that laboratory conditions would underestimate mechanical work expenditures in the field. These differences however, were shown to be reduced at work intensities approximating $\dot{V}O_{2max}$. The trend observed in this study clearly identifies the difficulties associated with reproducing similar reactions from two distinct conditions of cycling. The two laboratory conditions and field cycling each have demonstrated very different sensitivities towards equivalent work stress.

Representation of field performances during laboratory testing cannot depend on the assumption that the tasks are similar simply because the mode of exercise used was identical. Similarly, observing specificity of performance in terms of equipment, work protocol and cycling mechanics may not be a sufficient criteria to ensure that the exercise response in the laboratory is equivalent to that in the field. Information obtained in laboratory testing should be supported by field tests which can be used to identify and validate threshold intensities such as the lactate threshold. The use of HR monitoring in the field should predominantly be used to identify training targets and used in conjunction with laboratory and field tests to assess training responses. Finally, heart rates cannot always be used as an indicator of work stress when attempting to equate similar workloads performed under different conditions.

CONCLUSION

(1) Field cycling demonstrated that laboratory conditions would overestimate the oxygen consumption in the field.

(2) Crank torque measurements suggested that laboratory conditions would underestimate mechanical work expenditures in the field.

(3) Field cycling showed similar responses in $\dot{V}O_2$, ACT_{60} and PCT at intensities nearing maximal effort.

(4) Race ergometer cycling and treadmill cycling demonstrated similar relationships at all workload intensities.

(5) Similar HR generated in FC, RE and TC were not associated with the same $\dot{V}O_2$, ACT_{60} or PCT for each condition.

As a result of the preceding conclusions, it seems reasonable to state that:

(1) HR cannot always be used as an indicator of work stress when attempting to equate similar workloads performed under different conditions.

(2) The use of target HR based on laboratory testing should be supported with both a progressive and steady state field test.

(3) Laboratory performances should not be assumed to be representative of field performances where such activities are dependent upon a number of mechanical variables which may significantly alter performance efficiency as in cycling (ie. cadence, posture, seat height, crank arm length, pedal type).

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Appendix A

CHAPTER 1

THE PROBLEM.

Introduction and Rationale.

Heart rate is commonly used to describe the stress placed on the cardiorespiratory or oxygen transport system associated with physical performance in the field. Both the coach and the work physiologist use heart rate to determine the energy cost and work stress associated with a given task when assigning a training or testing work load (Faria, 1984; Ilmarinen et al., 1984; Jones et al., 1984; Astrand and Rodhal, 1986; Nielsen and Meyer, 1987; Karvonen and Vuorimaa, 1988). Initially a determination of the relation between oxygen consumption ($\dot{V}O2$) and heart rate (HR) is established in a laboratory under standardized conditions and the actual energy production in the field is then estimated from this relationship (Astrand and Rodhal, 1986). Use of this methodology depends strongly on the fact that a linear relationship exists between HR and workload (WL) and that the slope of the relationship remains constant. It has been established that a reasonably linear relationship exists between HR and work rate, particularly at moderate levels of exercise (Booyens and Harvey, 1960; Pugh, 1974; Kovac et al., 1975; Christensen et al., 1983; Washburn and Montoye, 1985; Astrand and Rodhal, 1986). Astrand (1960) and Steinbacker et al. (1986) noted that this relation is individually unique and dependent upon the age, sex and physical fitness of the individual. Others have concluded that various factors such as size of working muscle groups (Bevegaard et al., 1966; Kovac et al., 1975), static work component (Kiblom and Persson, 1981, Nielsen and Meyer, 1987; Maas et al., 1989), steady or non-steady state work (Fernandez et al., 1974), ambient temperature (Leblanc, 1957; Brown et al., 1985), stress (Astrand and Rodhal, 1986) and dehydration (Brown et al.,1985; Astrand and Rodhal, 1986) modify the slope of the linear response. Such modifications in response can affect the reliability and consistency of data collection in the field where it is common to have variations in any number of these factors from day to day. The need for a way of controlling these factors has stimulated many investigators to seek an easier more efficient setting for collecting information (Faria, 1984; Astrand and Rodhal, 1986). Laboratory investigations over time have become the ideal environment for reseachers to evaluate performance responses in athletes. The important factor that makes the laboratory an ideal environment is the control that it can provide over many extraneous factors.

The second assumption which must be met is that the slope of HR response to workload remains constant regardless of the mode of exercise. Researchers have long held the belief that, so long as the testing mode is identical with the athletes specific sport activity or work performance requirement, the information extracted from the laboratory can then be applied to field situations. Various authors have reviewed and demonstrated this point (diPrampero et al., 1971; Stromme et al., 1977; Wilmore, 1984 and deBoer et al., 1986). However there is some disagreement by investigators in defining task similarity. In other words, just how completely should the laboratory protocol represent the actual field situation. Evidence indicates that the physiological parameters such as HR and $\dot{V}O2$ can be significantly influenced in top level athletes by the slightest change in equipment (Shennum and deVries, 1976; Nordeen-Snyder, 1977; Faria et al., 1978; Carmichael et al., 1982; Ribisl et al., 1982; Moffat and Sparling,

1985) and by the way in which the rate and force are applied to accomplish the workload (Seabury et al., 1976; Hagberg et al., 1981; Faria et al., 1982; Croissant and Boileau, 1984; Coast and Welch, 1985). Certain authors have stressed that there is a lack of consistency in laboratory protocols and that these inconsistencies result in an inaccurate representation of true field conditions (Coast and Welch, 1985; Nielsen and Meyer, 1987). Therefore in order to accept this methodology as valid and reliable it must be demonstrated that laboratory simulation of an activity generates physiological response patterns that are representative of those achieved in the performance of the task in its natural or competitive setting.

The preceding might be accomplished by direct assessment of the heart rate work rate relationship in the field, thus providing an ideal way of analyzing an event in its natural state. However the various methods available too date are not without serious limitations. One conventional method has been to utilize a Douglas bag to store gas for determination of volume and gas concentrations (deGroot et al., 1983; Louhevaara and Imarinon, 1985; Astrand and Rodhal, 1986). The Krofranyi-Michaelis gas meter has also been widely used for measuring $\dot{V}O2$ (Louhevaara and Imarinon, 1985). Unfortunately both methods are rather laborious and have many limitations in practice, including a restriction to single load situations (Louhevaara and Imarinon, 1985; Astrand and Rodhal, 1986). A new portable instrument, the Oxylog (P.K. Morgan Ltd., Chatham, Kent) has been introduced to measure and show directly $\dot{V}O2$ and ventilation volume (Harrison et al., 1982; Louhevaara and Imarinon, 1985; Ikegami et al., 1988). This system is however limited by a range for $\dot{V}O2$ calculation of 0.25-3.00 $L \cdot min^{-1}$ and by its high cost (Harrison et al., 1982; Louhevaara and Imarinon, 1985). Unlike all these methods, heart rate recording is non-invasive, inexpensive and does not interfere with the performance of the athlete. The obvious fact is that direct field analysis is both a costly and time consuming venture whereas simulated conditions provide a more stable controlled environment in which to extract information and provide training cues for use in the field.

Cycling also imposes unique problems in the direct collection of metabolic and work rate data and as a result, little information identifying actual field demands of cycling is available. There have been studies defining methods for estimating energy expenditure in cycling (Whitt, 1971; Pugh, 1974; Marion and Leger, 1987) and other physiological studies limited to a descriptive qualitative analysis (Nelson and Craig, 1978). On the other hand there is an abundance of information regarding the physiological analysis of cycling within the laboratory. Such studies have reviewed a variety of components such as: pedal frequency (Gaesser and Brooks, 1975; Hagberg et al., 1981; Faria et al., 1982), seat height (Laurence Shennum and deVries, 1976; Nordeen-Snyder, 1977), crank length (Carmichael et al., 1982; Conrad and Thomas, 1983), posture (Faria et al., 1978), toe clips (Davis and Hull, 1981; Ribisl et al., 1982; Brodowicz et al., 1982, Moffat and Sparling, 1985) and other variables with respect to their relation to the physical stress associated with the task. These parameters have been assessed based on changes in physiological variables usually defined by HR, $\dot{V}$O2 and ventilation ($\dot{V}$e). However, use of these results for field applications demands certain cautions. For example, there is information to suggest that the use of the traditional cycle ergometer may not be representative of the performance profile of the cyclist in the field (Ricci and Leger, 1983) and yet this system is consistently used to establish a HR/VO2 relation. Moreover, the fact that a linear relationship exists for an individual during a given condition has not been reliably determined to be fixed or stable enough to provide the basis for describing physiological stress on different work tasks. Certain authors have confirmed that although there is a high correlation coefficient between HR and $\dot{V}$O2, during progressive work, the slope and intercepts of this relation can vary considerably from day to day, thus leading to poor agreement between duplicate estimates of energy expenditure and frequently to unreliable estimates of physiological values (Christensen et al., 1983).

Therefore, the following study has been designed to investigate the validity of applying laboratory measurements of HR/Work relationships to field applications.

Statement of the Problem.

This study has been designed to examine the time-course and slope of cardiovascular (Heart Rate - HR), metabolic (Oxygen Consumption - $\dot{V}O2$) and mechanical (Peak Crank Torque and Average Crank Torque - PCT and ACT_{60}) variables in response to progressive and steady state exercise employing laboratory simulations of cycling, race ergometer (RE) and treadmill cycling (TC) and cycling in the field.

The study had three objectives:

(1) to measure $\dot{V}O_{2max}$, HR_{max} in response to RE and TC.

(2) to measure $\dot{V}O_2$, HR, PCT and ACT_{60} in response to road cycling at heart rates identified with LT-10%$\dot{V}O_2$, LT and LT+10%$\dot{V}O_2$ determined from the maximal aerobic test performed on the RE.

3) to measure $\dot{V}O_2$, HR and PCT and ACT_{60} in response to RE and TC while performing at work rates equivalent to those performed in the field.

Hypothesis.

Given that physiological stress and mechanical conditions are held constant within the restrictions of cycling on a racing ergometer and treadmill apparatus it was hypothesized that the response of cardiovascular (HR), metabolic ($\dot{V}O2$) and mechanical variables (PCT and ACT_{60}) would remain the same for all test conditions.

Limitations of the Study

The subject population was made up of 8 experienced volunteer cyclists. These cyclists had cycled on a regular basis and had some form of competitive experience.

Each of the subjects were asked to perform at the human performance laboratory at the University of Ottawa, no fewer than five times during the course of the study.

Definition of Terminology

AVERAGE CRANK TORQUE (ACT_{60})- is the intergration of the area defined by the force displacement for 1 complete revolution of the crank arm. The measure is representative of impulse - N·s.

HEART RATE (HR) - is the number of ventricular beats per minute as counted from records of the electrocardiogram or carotid or radial pulses.

LACTATE THRESHOLD - is the intensity at which blood lactate values demonstrate in increase of 1 mmol or greater with subsequent increases in work loads.

OXYGEN UPTAKE (VO2) - is the volume of oxygen (at 0°, 760 mmHg, STPD) extracted from the inspired air, usually expressed in absolute units as litres per minute ($\dot{V}O2$) or in relative units as $ml \cdot Kg^{-1} \cdot min^{-1}$. If the oxygen content of the body remains constant during the period of determination, the oxygen uptake equals the volume of oxygen utilized in the oxidation of metabolic substrates. One litre of oxygen consumption corresponds to 19.7 to 21.1 KJ (4.7 to 5.05 kcal) of energy liberation from fat or carbohydrates respectively.

PEAK CRANK TORQUE (PCT)-is the maximal force displacement measured from the baseline for one complete revolution of the crank arm-360 degrees. The measure is equivalent to a newton force value (N).

PULSE RATE - is the frequency of pressure waves (waves per minute) propagated along the peripheral arteries, such as the carotid or radial arteries. In normal, healthy individuals, pulse rate and heart rate are identical.

CHAPTER 2

REVIEW OF LITERATURE.

The significance of HR as a tool for analysis.

The task of the coach and sport scientist in the field is to assess the stress imposed on the athlete by the total stress of the work and the working environment, (the same is true for the work physiologist). Measuring the rate at which the work is being done ie. the workload, allows the matching of this rate with the athletes (or workers) ability to perform the task. The development of lightweight electronic instruments and devices capable of recording and transmitting impulses by telemetry, or by direct recording with the aid of portable miniature recorders, has made it possible to study a variety of physiological functions in the person exposed to different types of work stress, including athletic events (Astrand and Rodhal, 1986).

The underlying principle upon which the process has been validated has been the linear response which exists between heart rate and work rate (or oxygen uptake). This relation is the framework from which most of the modern circulatory exercise tests have been developed. Similarly, it is common practice to employ these tests to establish a HR/work rate relation for an individual which serves to identify the cardiorespiratory stress the same individual faces while performing certain tasks or exercises. By monitoring HR information in the field the energy cost associated to the field work may be calculated. This process has been adopted by both the work and sport physiologist for it represents an efficient and effective way of describing field related response profiles. Although direct measure is possible, these methods are not without serious limitations. One conventional method has been to utilize a Douglas bag to store gas for determination of volume and gas concentrations (deGroot et al., 1983; Louhevaara and Imarinon, 1985; Astrand and Rodhal, 1986). The Krofranyi-Michaelis gas meter has also been widely used for measuring $\dot{V}O2$ (Louhevaara and Imarinon, 1985). However both methods are rather laborious and have many limitations in practice, including a restriction to single load situations (Louhevaara and Imarinon, 1985; Astrand and Rodhal, 1986). A new portable instrument, the Oxylog (P.K. Morgan Ltd., Chatham, Kent) has been introduced to measure and show directly VO2 and ventilation volume (Harrison et al., 1982; Louhevaara and Imarinon, 1985; Ikegami et al., 1988). This system is however limited by a range for $\dot{V}O2$ calculation of 0.25-3.00 $L{\cdot}min^{-1}$ and by the high cost (Harrison et al., 1982; Louhevaara and Imarinon, 1985). Unlike all these methods, heart rate recording is non-invasive, inexpensive and does not interfere with the performance of the athlete.

The evidence gathered over the years has repeatedly confirmed that a linear relation exists between HR and work rate (or oxygen uptake). As early as 1907, Benedict reported that changes in the pulse rate could be correlated with changes in heat production in any one individual which had been subsequently confirmed in later work. Based on their observations the investigators speculated that pulse rate might provide a practical and satisfactory way of measuring total metabolism. Subsequent investigations have produced evidence to suggest that the process might indeed be possible. Further researcher confirmed that a linear relation did indeed exist between HR and work rate (or oxygen uptake). It was also established that this relation was more constant and linear with increasing levels of exercise. Booyens and Harvey (1960) investigated the reliability of this relation by repetition of the measurements and, in the range of muscular exercise by comparing values for metabolic rate computed from the pulse rate with measured values. The investigators were able to conclude that the response is reliable and consistent and could provide a practical method of measuring metabolic rate under controlled conditions. Washburn and

Montoye (1985) confirmed the findings of earlier investigators. They studied the reliability of heart rate during dynamic exercise with various muscle groups and at different work intensities, specifically submaximal intensities of arm cranking and leg cycling exercise. Data analysis concluded that the reliability of heart rate increased with increments in workloads (submaximal) as identified by the increased correlation from 0.23 to 5 W to 0.85 and 0.89 to 30 W and 50 W respectively for arm cycling. Similarly with leg cycling, repeated measures showed a high degree of reliability at all power outputs with R ranging from 0.91 during no load cycling to 0.95 at 100 W. Consistent with these results was the fact that no significant difference for oxygen consumption at rest or during either arm or leg exercise were shown over testing sessions. The authors concluded that the HR/$\dot{V}$O2 relationship is reliable on test-retest situations and results in a higher correlation with well practised tasks versus that for novel tasks.

Christensen et al.(1983) supported the conclusions of the previous authors that a relation between HR, $\dot{V}$O2 and Work existed and confirmed that this relation demonstrated greater linearity and consistency at higher levels of work. However, in contrast to previous reseachers, it was revealed that although the traditional relationship between $\dot{V}$O2 and HR existed for a given test situation, the slopes and intercepts varied considerably from day to day. They concluded that the technique of estimation based on the HR/$\dot{V}$O2 relation is poor when used for ordinary daily activities with low energy expenditure. The authors of this study identified that field estimates of energy expenditure are not reliable enough to determine exact task related energy cost. Astrand et al. (1973) determined energy expenditure in 14 fishermen engaged in fishing. This was determined by direct measurement of oxygen uptake by use of a Douglas bag and by indirect assessment based on continuous recording of heart rate. A standard bicycle ergometer test was employed to determine the

HR/VO2 relation. Like many field studies of this type, the constantly changing conditions made it almost impossible to assess average energy requirements by direct measurements of oxygen uptake. On the other hand it was noted that the indirect approach provided a more realistic picture of the total work load during the entire period at sea. The authors concluded that in spite of the above mentioned limitations, the values of the oxygen uptake during the different activities were on the whole, in fairly good agreement with values obtained on the basis of the heart rate. However, Astrand and Rodhal (1986) noted that the process can indeed yield a certain range of discrepancy in its measure. A recent study of 24 direct measurements of oxygen uptake were compared with the oxygen uptake calculated from the recorded heart rates in 6 fishermen. The calculated values deviated from the measured ones in both directions by as much as + 15% but unlike Christensen et al. (1983) it was found that a remarkable reproducibility of the day-to-day results in the same individual doing the same work existed. The mean heart rates were practically the same for all 3 days, and the distribution curves, when superimposed, showed the same shape (Astrand and Rodhal, 1986).

Based on these investigations, the use of the recorded heart rate in the field compared with the heart rate at known workloads on an ergometer, has been determined useful as a basis for the estimation of the work load when the work operation involves the use of the same large muscle groups (Astrand et al., 1973; Rodhal et al., 1974; Washburn and Montoye, 1985, Astrand and Rodhal, 1986). This procedure is acknowledged to have a degree of error associated with it (Christensen etol., 1983) however for practical purposes the information serves to identify stress situations and task related differences(Astrand et al., 1973; Astrand and Rodhal, 1986). The available information in the literature provides insufficient evidence to justify (or validate) the process as it applies to athletic situations. It is probable that this lack of information is representative of the difficulties associated with obtaining direct measurements in many of the sports. Unlike occupational and industrial type work situations which are less dynamic and generally quite stable in terms of the functional operating area, many sport activities are highly dynamic and quite physically demanding (Astrand and Rodhal, 1986). There is evidence to indicate that using HR monitoring can underestimate the actual competitive stress that the athlete might encounter. A group of alpine skiers were tested in the laboratory by a standard test from which the oxypulse ratio was determined. A particular world class alpine skier had his HR monitored in an actual competitive event. The starting HR was as high as 160 beats·min^{-1} and increased to maximal levels at the end of the run at 207 beats·min^{-1}. The next day following the race two skiers were equipped with the Douglas bag apparatus and were asked to perform the same run. The recorded values indicated that the energy cost associated with the run was equivalent to 78% and 82% of the individuals MVO2 and the recorded HR values represented submaximal values (similar times equivalent to the actual race were recorded). This observation identifies that the event itself represented an added stress leading to an elevated heart rate that would normally not be accounted for in regular laboratory sessions or even during field practice sessions. It also identified the relative importance that HR monitoring may have in identifying these stress situations. This would allow the athlete to be better prepared under such conditions. It does identify that the same work condition can be represented by different HR. The added stress alters HR without there been an increase in the actual workload or physical demand of the task. However, it should be pointed out the same skier analyzed in the competition was not used for the gas collection phase. Drawing any valid conclusions based on the limited scope of the study would not be justified. This investigation does however identify the lack of valuable information that is available with respect to sporting events and HR monitoring.

In view of the fact that HR monitoring has evolved in the sporting community as a routine function, it would seem consistent that the methodology would warrant some form of scientific scrutiny. And yet, sport related verification of the process has been limited and the process unsubstantiated. Corroborating the HR to Work relation for sport related activities with information related to non-athletic type activities might not be a valid practice considering the extreme difference in the demand and tolerance associated with the task, especially with elite level performance routines as illustrated with the alpine skiers. However the information is not without some benefit to our understanding of the simple mechanism and it is in this light that we must focus upon the available information. It is evident that the problem is not whether this relationship is linear or not, for a reasonable linearity has been documented. The problem is whether this practice is a valid one and one which can be demonstrated to be maintained (or reproduced) under different task situations of similar work rates without affecting the slope and intercepts of the relation.

Karvonen and Vuorimaa (1988) explained that it is possible by recording the heart rate during a training session or a segment of training session to evaluate training routines and develop upon training programs in such cases where target heart rates have been pre-determined by laboratory investigation. Evidently it seems that the sport scientist has readily accepted the validity of the procedure with insufficient information to support its practice. Although HR is commonly used a certain degree of wariness must be expected over its application when it is considered that there is a lack of information to support the soundness of this practice. There are many factors that have been identified in the literature has having an influence in modifying the slope and intercepts of the relationship. A review of these factors might give us some information in which to assess the logic of this process.

Factors affecting heart rate.

Irrespective of the type of sport or workload situation this relation has been shown by Astrand (1960) and Steinbacker et al. (1986) do be a function of the individual alone and one which cannot be used to analyze group performances. These authors have shown that the relation is affected by the sex of the individual, age and level of physical fitness. Steinbacker et al., emphasized the fact that although heart rate increases with workload, there is a considerable variation in the values observed resulting from anthropometric differences and different levels of individual physical fitness. Consistency and reliability of the relation are known to be influenced by a number of other factors. Such factors as the size of working muscle groups, static versus dynamic work components, steady or non-steady state work, ambient temperature, stress and dehydration. These factors are known to modify the slope of the response. Leblanc (1957) identified from his work that caution should be practiced when extrapolating information from HR in the field. Results from his study revealed that ambient temperature has an effect of altering the correlation between pulse rate and oxygen consumption. With increases in ambient temperature heart rate at a given workload increased. Booyens and Harvey (1960) concluded that when the pulse rate is being partly determined by other factors than metabolism, as in ambient temperature, it is still a valuable measurement in its own right and a better indication of the physiological load or stress the situation imposes than a measurement of metabolic rate alone. In a comparison of laboratory cycling versus simulated cycling, Brown et al. (1985) evaluated the effect that the outdoor conditions could have on the cyclist and how this might affect laboratory values. Outdoor environmental conditions were simulated with fans and lamps and were contrasted with standard no-wind, no-sun laboratory conditions. During outdoor cycling mean heart rate was 7-13% higher than under laboratory conditions suggesting a greater stress for a similar external work rate.

A very important observation identified that the thermoregulatory stress was greater under no-fan, no-lamp laboratory condition than during simulated outdoor conditions. The cooling wind encountered in actual road cycling apparently reduces thermoregulatory and circulatory demands compared with stationary cycle ergometry indoors. The authors note that failure to account for this enhance cooling may result in an overestimation of the physiological stress of actual road cycling. They also make note of the fact that the recorded core temperature and heart rate rose throughout the period of laboratory cycling at a constant velocity indicating the need for caution in inferring relative metabolic rate from heart rate during prolonged exercise without adequate rehydration.

Another factor requiring consideration relates to the method in which the work is performed, steady state versus progressive rates of work. It may now be generally agreed that the oxygen consumed per unit of physical work is less during progressive exercise than during steady state (Astrand and Rodhal, 1986). The importance of this effect can best be demonstrated by the fact that laboratory testing used to assess athletic fitness is undertaken by a progressive workload protocol. With this information, inference to field situations are made. The problem then follows when the training protocols differs in structure from the laboratory test. Athletic training incorporates for the most part steady state training where intensities are modified about a pre-determined threshold for specific time periods. Fernandez et al. (1974) demonstrated the oxygen consumption measured by the steady state method is not the same as that measured by the progressive method for identical workloads resulting in an altered oxygen-pulse ratio.

Nielsen and Meyer (1987) identified the importance of this factor as well as the importance of considering the type of muscular work (dynamic vs static) performed in the work condition. In their study, they compared $\dot{V}O2$ measured directly by a portable oxycon during industrial work to $\dot{V}O2$ calculated from HR recorded simultaneously. The $\dot{V}O2$-HR relation was established for submaximal exercise on a bicycle ergometer in the work environment itself. The results indicated a definite overestimation of energy expenditure with HR data. They concluded that the static component of the industrial work was the major reason for the overestimation of energy expenditure from HR data. They noted that this overestimation becomes even more obvious in cyclic work (non-steady state) with a low degree of dynamic activity. Using a cycle ergometer to establish the $\dot{V}O2$-HR relation was determined to be an inappropriate test. They concluded that a better estimation of the metabolic rate might be obtained by the use of a standardized test, more representative of an industrial situation (including static work or arm work). The study defined the sensitivity of the HR/$\dot{V}O2$ relation to those factors which are known to alter the slope and intercepts of the relation.

Task_specificity.

It is believed by certain researchers that it is possible to define within a degree of certainty the cardiorespiratory stress in field evaluation using HR so long as that methodology used to define the relation by laboratory investigation simulates the conditions as best as possible and is standardized (Astrand et al., 1973; Rodhal et al., 1974; Washburn and Montoye, 1985; Asrand and Rodhal, 1986). Other emphasize that prudence should be practised when evaluating field performance based on laboratory investigations (Christensen et al., 1983; Nielsen and Meyer, 1987).

Wilmore (1984) concluded that the testing mode should be identical with the athletes specific sport activity in order to ensure that the data is representative of the performance in the field. Failure in observing this fact consequently results in either an over or under estimation of the physiological load. This fact was supported by the work of Vokac et al. (1975). Their investigation of the oxygen-heart rate relationship in leg and arm exercise, sitting and standing demonstrated significant differences between exercise modes. The experiment was designed to show the development and the order of magnitude of differences between arm and leg exercise at increasing workloads in parameters that may be applicable in field work and secondly to evaluate the reliability of the heart rate for the estimation of the circulatory stress and workload in field studies. Experimental results revealed that at the same absolute load at submaximal effort, leg cycling, arm cycling sitting and arm cycling standing, there were no differences at the lowest workloads and from rest to a work rate of 300 kpm·min^{-1} the oxygen uptake and heart rate rose linearly the same. Beyond 300 kpm·min^{-1} both types of arm work demonstrated increased cost as both heart rate and oxygen uptake deflected and increased much quicker. The authors noted that oxygen uptake at maximal effort was 15-20% lower in arm work than in leg exercise, whereas the opposite is true at submaximal work levels, identifying the importance of defining the trends from rest to max in comparative analysis. Evident by these results is the fact that maximal response cannot be used a valid indicator of submaximal trends. Steinbacker et al. (1986) demonstrated during laboratory analysis of rowing ergometer exercise that this difference in max $\dot{V}$O2 can indeed be demonstrated at submaximal levels. A multi-stage test was performed beginning with a work load of 150 W and increasing by 50 W every 2 minutes up to exhaustion. $\dot{V}$O2 and HR for each working stage were measured and the regression line of $\dot{V}$O2 on the workload were calculated for all 10 elite rowers and 6 elite cyclists. For both groups, $\dot{V}$O2 at submaximal workloads was significantly higher on the rowing ergometer than on the bicycle ergometer while an absence of a significant change in all workloads was noted. There was no significant difference in $\dot{V}$O2 max between the groups. This fact confirms the conclusion made by Vokac et al. (1975) that submaximal responses may not be consistent and linear up to maximal work rates.

Specificity in performance is an important criteria for selecting a laboratory protocol as identified by Stromme et al. (1977). Maximal aerobic power was assessed in specifically trained athletes and these values were compared with ones achieved by running. Subjects included female and male cross-country skiers, rowers and cyclists. Individual differences of 12.2%, 5.4%, 14.3% and 7.5% for these respective groups were noted when compared to running. The authors felt it was warranted as a conclusion that in order to obtain objective information about both the incremental differences with increasing work intensity and $\dot{V}O2max$, it becomes important to select an appropriate test situation, that is, a test involving large muscle mass and optimal use of the specifically trained muscle fibres. DiPrampero et al.(1971) measured $\dot{V}O2$ during actual rowing in a rowing shell by direct analysis and compared it with that data collected during simulated rowing ergometer. The resultant oxygen-pulse ratio identified for each task showed that the responses were similar. They concluded that heart rate is a reliable source of information and is the link between field and laboratory evaluation.

The information derived from these studies describe the main criteria required to ensure reasonable representation of field task by laboratory testing. These criterias include similarity in large muscle groups, mechanical motion and work protocol. Daub et al. (1981) noted that this concept of specificity goes beyond the need associated with testing alone and states that this fact should be maintained in training procedure as well. deBoer et al. (1987) also emphasized the importance of practising the concept of task specificity, supported by their analysis of speed skaters while skating on rollers and by actual speed skating. Biomechanical and physiological response were both compared. The study looked at 8 elite speed skaters who underwent two work situations, namely speed skating and roller skating at maximal exertion. The skaters were analyzed for biomechanical parameters and skated in pairs for the first stage. The second stage involved the physiological assessment of both tasks again while skating in pairs. Coupling of the skaters was used to ensure that the actual conditions be conserved and the competitive atmosphere be maintained. Heart rate was continuously measured by telemetry. Oxygen consumption was measured by the use of portable Douglas bag. Gas analysis was taken in the last 30 seconds of the test. Mean values of heart rate during the last lap of each test were used for comparison.

Analysis of results showed no significant differences could be found between heart rate, oxygen consumptions and power output. The calculated oxygen pulse ratio and the ratio of external power/energy equivalent of oxygen consumption $(Pf/\dot{V}O2)^2$, were similar for both types of skating. From the similar values of HR (174 ± 12.2 and 176 ± 14.5) and the magnitude of the RER RER
RER (1.04 ± 0.1 and 1.16 ± 0.1) it was evident that each tests reflected an equivalent performance in both roller and ice skating. In terms of the biomechanical aspects, the work per stroke, stroke per frequency, and the power loses were equal. A difference in the speed of skating was evident. The speed achieved while speed skating was was 9.78 $m.s^{-1}$ compared to 8.04 $m.s^{-1}$ for roller skating. This difference was noted to be a function of the resistance due too surface friction. The roller skating skate having a higher coefficient. It was concluded that for training purposes one should bear in mind that, due to this difference in maximal speed, other variables, such as heart rate should be used to compare intensities between roller and ice skating. Although there was a significant variation in the net resistance, the absolute workload associated with the task was similar. This observation lends support to the observed fact that HR c. be used as an index of work output. A second point which is evident is the degree of

similarity in exercise mode that must be observed. As the biomechanical data demonstrates, each task was indeed mechanically similar. Although the study identifies that the responses are similar, the information does not necessarily allow us to define the degree of similarity in protocol and task execution that must be used observed in order to ensure identical cardiovascular, metabolic and mechanical similarities. However, it would have been necessary to identify a condition less specific to each as a basis for a more detailed comparison. Lacking, is this information and a profile of submaximal workloads.

The degree of specificity required in a test protocol has an important effect in the maintance of a valid and representative HR/$\dot{V}O2$ relationship to the field. There are a number of variables that have been documented to affect the validity and reliability of this relationship and demonstrated that caution must be used when making conclusions based on laboratory tests.

Physiological Response in Cycling.

Heart rate has been extensively used as an indirect measure of physiological responses. There is however one very important assumption associated with the use of HR:

-heart rate is representative of the work load or work stress in the performance of a task.

In evaluation of sport performance in the laboratory with ergometric devices, evidence previously discussed strongly supports the fact that the best responses achieved by an athlete are sport specific. Faria (1984) noted that researchers have become more conscious of the failure of allowing cyclists to ride their own bicycles during tests. This adaptation is a realization brought on by the fact that recent research on submaximal and maximal response indicate that physiological relationships from one task to another may vary depending on how closely the work situation duplicates the task being analyzed. Such adaptations are been incorporated to ensure that energy cost associated with each task are equivalent.

Hagberg et al. (1978) compared the physiological response of cyclist at maximal effort on three different tasks:

1) treadmill running
2) a cycle ergometer
3) motor-driven treadmill cycling

The three $\dot{V}O2$ maximum tests were administered in a random order within a 2 week period. All three tests followed a progressive test protocol. As part of a first time experiment the efficiency of bicycling on a treadmill as a method of simulating road racing conditions was tested. The test protocol required that the subject ride his road-racing bicycle on motor driven treadmill at 20 mph. The grade was increased 0.5 degrees each minute from an initial setting of 2 or 3 degrees. The similarity in $\dot{V}O2$ max achieved while cycling on the cycle ergometer and on the motor driven treadmill, 65.0 ± 3.4 ml·kg^{-1}·min^{-1} and 65.5 ± 3.2 ml·kg^{-1}·min^{-1} respectively, identified the possibilities of using treadmill cycling as an excellent way of representing field cycling. The authors noted that treadmill bicycling with the subject riding his own road racing bicycle seems to be an excellent method to simulate conditions encountered in actual competitive situations. The tests were noted to be similar with respect to the workload each imposed, but these workload values were subject to some variation due simply that the calculations were based on estimations only. Although the authors concluded that treadmill and ergometer cycling were physiologically similar, Rici et Leger (1983) demonstrated disagreement with this statement. Results from velodrome cycling revealed that M$\dot{V}O_2$ was significantly lower than that of bicycle ergometry. The $\dot{V}O_2$ max was 15% lower than that of the bicycle ergometer value. This is in contrast to the conclusion made by Hagberg et al. that treadmill cycling is a reliable source for assessing actual field conditions. These results are important when it is considered that the track test is representative of the natural situation and a condition which trained cyclists normally exert themselves maximally. In reviewing the protocols used by Rici et Leger (1983) for the two cycling tests, the load was increased every two minutes. This increase was of 30 watts for the cycle ergometer, at 60 rpm after the initial two minutes at 120 watts. At the velodrome the initial speed was 25 km/hr, increasing by two km/hr until it reached 42 km/hr, thereafter increasing by one km/hr. Prerecorded sound signals emitted at specific frequencies were used to pace the cyclists at each stage of the progressive test. The cyclists had to move from one pylon to the next one between sound intervals which was easily done (± 5m). A value of 53.0 ml·kg^{-1}·min^{-1} was achieved during velodrome cycling and 62.4 ml·kg^{-1}·min^{-1} Interestingly enough, maximal heart rates were similar and maximal work calculated for each task were similar. On the other hand, mechanical efficiency ($\dot{E}$) during track cycling was higher compared to ergometer cycling. An obvious conclusion is that there is some contradiction which exists between these two tasks at maximal levels which may possibly extend to submaximal loads. It also raises questions regarding the validity of HR as a parameter of analysis for comparing performance response between actual and simulated tasks. The results do not support the expected consistency in the HR/$\dot{V}O_2$ relationship. As noted by the authors, the lower M$\dot{V}O_2$ max observed for the velodrome test as compared to the stationary bicycle test raises questions about the validity of the latter test as an indicator of true aerobic capacity of cyclists to perform endurance events on a track.

Recently, Marion and Leger (1988) concluded that peak $\dot{V}O2$ values as measured while cycling in the velodrome and that measured in the laboratory on an ergocycle at 80 rpm revealed no significant differences. However track peak $\dot{V}O2$ showed a non-significant trend to been lower in comparison to the ergocycle test, 4.87 L·min^{-1} and 5.24 L.min^{-1} respectively for the elite cyclists, contrasting the findings of Ricci et Leger (1983). The track protocol required that the cyclist ride his own bicycle at five different speeds. The first three were identical for all subjects (28.5, 33.0, 36.0 Km·hr^{-1}), while higher velocities were set according to the riders capacity to elicit maximal oxygen consumption. Speed was controlled in a similar manner as described by Ricci and Leger (1983). The laboratory test consisted of a direct peak $\dot{V}O2$ measurement using the Douglas bag method in which the gases were collected in the last minute of the multistage test. A Monark ergocycle was used and modified to allow the subjects to use toe clips with straps and cleated cycling shoes. The subjects pedalled at 80 rpm. However, in the last study, the lab test was conducted at 60 rpm and the cyclists used either road or track bicycles. The range of pedalling frequencies at maximal intensity on the velodrome was also higher 99.30 ± 6.15 as compared too 95.8 ± 4.12 which could have affected the mechanical efficiency of some riders. It should be noted that on the track, peak $\dot{V}O2$ was elicited in only 10 out of the 17 subjects, of which only 2 subjects included the elite athletes and 8 representing the non-elite group. The maximal speed achieved of 42.4 Km·hr^{-1} was closely similar to that achieved in the study by Rici and Leger (1983). A review of these two velodrome tests values suggests a lack of reliability with the protocol itself. It may be speculated that the differences are related to the differences in protocols used. However, both studies identify some inconsistencies with laboratory measures suggesting that some variability in performance is possible. An earlier study by Pugh (1974) demonstrated that similar $M\dot{V}O2$ values can be achieved while cycling outdoor when compared to cycling on cycle ergometer (5.12 L·min^{-1} and 5.10 L·min^{-1}). The maximal speeds achieved in outdoor tests were similar to those of previous studies, 41 Km·hr^{-1}. In the analysis of the ergometry cycling, the traditional linear relationship between $\dot{V}$O2 and work rate was observed and remained linear to maximal levels. In a comparison of ergometry cycling with outdoor cycling, the relationship between pedal frequencies on the ergometer and pedal frequencies in outdoor cycling revealed that at low levels of work (submaximal) and at $\dot{V}$O2 less than 2.0 L·min^{-1}, the frequencies associated were slower in outdoor cycling. At work rates above 2.0 L·min^{-1} frequencies were similar which reflects a difference in efficiency at lower levels of work, unlike Ricci and Leger (1983) who demonstrated this greater efficiency up to maximum levels.

The evidence available from these investigations suggest that similar maximal aerobic performance values may be achieved in the field and in the laboratory. However it should be noted that Pugh (1974) and Ricci and Leger (1983) have identified that these similar task are subject to differences in mechanical efficiency especially at low work rates which suggests that the energy cost at submaximal loads may not necessarily be identical with respect to the cardiorespiratory stress these loads impose. This point must considered when reviewing the different protocols used in the analysis. In all cases presented a traditional progressive multi-stage test protocol was used in which the subjects pedalled at a similar cadence through the whole test and where the workload was increased by added mechanical resistance. In comparison, the field protocols required that the subjects increase their speed in order to achieve an increased work stress, executed by changes in cadence and gear combination. However, changes in cadences and gear ratios have been shown to result in variations in physiological efficiency for a given work load (the mechanism involved will be discussed later). With reference to the ergometer, Croissant and Boileau (1984) identified from individual comparisons of cyclists on a cycle ergometer that significant differences in steady-state $\dot{V}$O2 ranging from 10 to 29% for different combinations of rate and load at a constant power are possible. A review of the different laboratory cycling protocols revealed that most of the studies utilized different cadences and load increments. With respect to field cycling Pugh (1974), Ricci and Leger (1983) and Marion and Leger (1988) have identified that when $\dot{V}$O2 is expressed as a function of cycling speed, it is evident that a curvilinear relation exists. This relation suggests that the economy of cycling indoors in a laboratory setting may not be similar to that achieved while cycling outdoors, especially at submaximal loads.

The importance of understanding how each system works its respective environment before it is tested with a different setting, method and demand is highlighted by these studies. The fact that similar M$\dot{V}$O2 values were achieved cannot be the single criteria for establishing the soundness of a test protocol for testing purposes and establishing submaximal load comparisons. Marion and Leger (1988) determined that since no significant difference was observed between track and ergocycle peak $\dot{V}$O2, the use of the 80 rev·min^{-1} protocol for laboratory evaluation of racing cyclists was a valid test for cyclists. This conclusion may be valid with respect to the determination of maximal aerobic capacity but not necessarily valid for establishing similar responses in the field where efficiency changes occurs at pedalling speeds above or below optimal.

Factors Affecting Physiological Responses In Cycling.

Pedalling Rate.

The available studies reveal a degree of discrepancy in the identification of an optimum pedal speed. Earlier work suggests that pedal frequencies as low as 40 - 60 rpm are most efficient. However such values do not explain how cyclists can maintain cadences as high as 90 - 110 rpm for long periods and at some points reaching 130 rpm or even higher. Seabury et al. (1976) investigated the interrelationship. Three college-age male subjects rode a Monark ergometer at 8 pedalling rate (30 -120 rpm) and at 4 power outputs (0, 500, 1000, 1200 kgm·min^{-1}). VO2 determinations were made and and using measured RQ, gross energy expenditure was derived. From their analysis it was found that a most efficient pedalling rate exists for each power output studied. The most efficient pedalling rate increases with power output from 42 rpm at 250 kgm·min^{-1} to 64 rpm at 2000 kgm·min^{-1} and the increase in energy expenditure observed when pedalling slower than "most efficient" is more pronounced at high power outputs than at low outputs. It was observed that there was an appreciable interaction between pedal rate and power output but the most efficient rate was significantly lower then previously reported values. The findings of Gaesser and Brooks (1975) also yielded decreasing efficiency with increments in speed. In both cases, this decrease in efficiency at the higher pedalling speed may have been due to the unskilled riders used in the study. It has been observed that unskilled riders, especially at high speeds, employ excessive body movement. Their lack of spinning technique accounts for mechanical inefficiency which contributes to a greater energy cost. In contrast the skilled cyclist pedals smoothly at high rpm without engaging muscle groups which do not contribute to pedalling speed (Faria, 1984).

Hagberg et al. (1981) investigated the effect of pedalling rate on submaximal responses of competitive cyclists. As such, the objective of the study was to investigate the effects of pedalling rate on the cardiovascular, respiratory and metabolic responses of competitive cyclists to a workload requiring 80% of their maximal $\dot{V}O2$ uptake ($\dot{V}O2$ max) while riding their road racing bicycles on a treadmill to simulate competitive cycling. The same responses were also measured during a series of trials with no external load being imposed on the cyclists to assess the effect of varying the rate of limb movements independent of external work rate. In the loaded situation, subjects rode at a gear ratio that was ascertained individually to be their optimum. As well, each subject rode the treadmill 2 gear ratios above and 2 gear ratios below. On the second phase of the experiment, the no load cycling, the cyclists rode their bikes at 80% MVO2 at 60, 75, 90, 105 and 120 rpm. The chains were removed from the bicycles to ensure that the only work done was that involved in moving the legs and turning the pedals. The results of the study showed that under no load conditions, $\dot{V}O2$, $\dot{V}E$ and HR rose significantly with increasing pedal frequencies from 60 rpm to 120 rpm. With respect to $\dot{V}O2$ this represented an increase from 7.5 $ml \cdot kg^{-1} \cdot min^{-1}$ to 19.3 $ml \cdot kg^{-1} \cdot min^{-1}$ and HR values changed from 74.3 bpm to 104.8 bpm. The unloaded cycling series shows that simply moving the legs more frequently does have a significant effect on many of the parameters. With respect to the loaded cycling, it was noted that with regards to the majority of the parameters, the changes in response increased with those gear ratios above and below the optimal levels. In other words, the values obtained for the cyclists preferred gear reflected the lowest levels (average values) with respect to $\dot{V}O2$ ($L \cdot min^{-1}$) at the preferred pedal frequency a value of 3.99 $L \cdot min^{-1}$ was obtained. The faster pedal frequencies elicited a value of +11.3% above the preferred value with +3.5% with slower pedal frequency. Heart rate was 179.6 bpm at the preferred frequency with values of +5.1% and +1.5% for faster and slower pedal frequencies respectively.

The data demonstrates the importance of maintaining similar cadence from one task to another. For as it can be noted, increases in energy cost are not due to changes in workload but due to a different cadence been used in the protocol. Faria et al. (1982) demonstrated similar conclusions. In their study each cyclist performed two six minute rides at each of three pedal rates (60, 100, 130 rpm) at two power outputs (800 and 1800 kpm). The gear used was kept constant. The task was performed on a motor driven treadmill with road racing bicycles. During each ride heart rate and oxygen consumption were measured each minute throughout the ride. Constant power output was maintained throughout the work period. The analysis revealed that at low power output $\dot{V}O2$ rises linearly with respective values of 31.38, 33.57 and 40.98 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ for pedal rates of 60, 90, and 130 rpm respectively. Faria et al. have demonstrated that the effect on efficiency of changing the pedal rate while the load is held constant is negligible at high power outputs. There appeared to be a significant advantage in employing a high pedalling rate at high power output. The faster pedalling rate yielded a smaller oxygen cost for the racing cyclist. Conversely, at high power output, oxygen consumption decreased with increasing pedal rate with values of 56.31, 54.78, and 53.56 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ at pedal rates of 60, 90, and 130 respectively. The importance of conserving both pedal rates and power output change when comparing two similar tasks is stressed by these results. This fact was also concluded by Coast and Welch (1985) who stated "there was a need for making the procedure of a series of tests that fit the subjects being used and not for the convenience of the investigators". Coast and Welch identified in their study that both HR and $\dot{V}O2$ differ significantly among pedal rates at equal power outputs. As well, it was shown through the results of the progressive test that both heart rate and $\dot{V}O2$ increased linearly at each pedal rate at increasing power outputs. As well, at each power output an optimum frequency was noted and that this optimum cadence increased with increasing power output. Unlike the previous studies, those results were demonstrated on a modified stationary bike.

Posture.

The ability to sustain prolonged work is dependent upon an adequate supply of oxygen to the working muscles. The mechanisms of high oxygen transport are affected by body position during work (Bevegard et al., 1963). Faria et al. (1978) noted that cycling posture is an important determinant of performance in cycling. They noted that cyclists generally assume two common saddle postures:

1) sitting semi-upright on the saddle with the hands resting on the uppermost portion of the handlebars.

2) sitting on the saddle while assuming a deep forward lean with the hands resting on the drop portion of the turned-down handlebars.

It was shown in the data analysis that all maximal values, M$\dot{V}O2$ and maxwork were significantly different from top bar position to the drop bar position. Heart rate however, remained constant from one condition to another. In terms of numerical differentiation, it was noted that maximal oxygen uptake (ml·kg^{-1}·min^{-1}) measured for the two cycling postures varied as much as 21%. Similarly, the drop bar position showed increased total work output and work output per kilogram of body weight by 16.7% and 28.5% respectively. The authors indicate that this is strong evidence to indicate that drop bar position enhances the individuals capacity to perform muscular work. Submaximal response, PWC170, showed that $\dot{V}O2$ increased by 4.08 ml·kg^{-1}·min^{-1} or 10% increase in the drop bar position. Conversely, HR did not change and remained similar in both positions. These results of the experiment revealed that submaximal response to cycling is significantly different from top bar position to drop bar position. These data demonstrate that body posture during cycling is crucial for optimum performance and is an important variable to consider when physiological comparisons of similar tasks are made, such as those by Hagberg et al., (1978); Faria et al., (1982) and Ricci and Leger (1983) where proper cycling form was not maintained during task performance on the stationary ergometer.

Toe Clips.

Important consideration must be accorded to such mechanical parameter as the use of toe-clips or cleated shoes. Davis and Hull (1981) noted that through proper application cleated shoes may increase pedalling efficiency and that the trained cyclist can benefit from there use. They found that the use of cleated shoes retards fatigue of the quadriceps muscle group. By allowing more flexor muscle utilization during the backstroke, cleated shoes distributes the workload and alleviates the peak load demand on the quadricep group. Both Ribisl et al. (1982) and Brodowicz et al. (1982) examined the physiological significance of toe-clips use. Brodowicz et al. examined the effect of toe clips use during cycle ergometry on the anaerobic threshold of competitive and non-competitive cyclists. Competitive cyclist exhibited a significant increase in $\dot{V}O2$ max at anaerobic threshold when using toe-clips. This difference was not identified to be significant in non-competitive cyclists. Ribisl et al. (1982) showed that competitive cyclists demonstrated a significant decrease in the rate of perceived exertion with the use of toe clips. A significant increase in $\dot{V}O2$ max was also observed. These findings suggest the obvious benefits that are associated with the use of toe clips and identifies the sensitivity associated with training responses. Unlike noncompetitive cyclist, elite competitive cyclist can demonstrate variations in efficiency simply with the use of toe clips. This point is supported by the work of Moffat and Sparling (1985). They noted that the use of toe clips resulted in lower oxygen costs (non-significant) at a given submaximal response than without toe clips.

Crank Arm Length.

The length of the crank arm has been suggested to be an important parameter in the achievement of optimal efficiency in cycling. Carmichael et al. (1982) found that was indeed the case. Pedalling efficiency was found to vary with upper leg length at a fixed crank length. Using 9 elite cyclists, Carmichael et al. examined the effects of varied crank length on $\dot{V}O_2$ and HR. These evaluations were made at constant power output and pedal speed. The cycling bouts were of 6 minutes duration at approximately 75% $\dot{V}O_2$max employing each of 6 crank lengths (150, 160, 170, 180, 190, 200 mm). The optimal crank length which was considered to be that which resulted in the lowest $\dot{V}O_2$ was found to correlate significantly with upper leg length. An important conclusion suggested that the crank length on most commercially available bicycles and ergometers is probably too long for most cyclists. Unlike the findings of Carmichael et al., Conrad and Thomas (1983) determined the prediction of optimal crank arm length cannot be determined from the length of a segment. However the crank lengths used varied only between 165 to 180 mm. Increments of only 2.5 mm were tested at a constant workload equivalent to about 80% of $\dot{V}O_2$max. Since no differences among any of the 7 crank lengths was shown with respect to $\dot{V}O_2$max, it was concluded that different crank arm lengths within the range tested do not influence cycling efficiency. However there was an insignificant increase in $\dot{V}O_2$ between increments.

Seat Height.

The effect of bicycle seat height variation has been investigated in terms of the mechanical efficiency associated with various seat heights. It has been suggested that saddle height can alter a cyclists ability to perform and maintain a given power output. Laurence Shennum and deVries (1976) investigated the effects of varying saddle heights on $\dot{V}$O2 during bicycle ergometer work at varying workloads. The experiment saddle heights used in this study were 100%, 103%, 106%, 109% and 110% of the measured leg length from ischium to floor. The workload protocol was set at 3 minute intervals for 50 Watts and increasing by 25 Watts up to 200 watts at pedal rate of 60 rpm. VO2 was shown to increase with each increase in saddle height. The most efficient height identified by the lowest $\dot{V}$O2 was found to be between 100% and 103%. It was concluded that in light of the data and earlier data showing power output to be maximized at 104%, the saddle height of choice should be approximately 103% to 104% of leg length. Nordeen-Snyder (1977) identified similar trends. The difference between the mean $\dot{V}$O2 at the 100 and 105% saddle heights were found to be significant at the 0.05 level of probability. A positive variation of 5% in saddle height produced a greater increase in $\dot{V}$O2 at the high saddle height than the decrease which occurred as a result of a negative 5% change in seat height. Analysis of kinematic patterns of the lower limb indicates that a major adaptation to increasing saddle height occurs and this was demonstrated to occur at the knee.

The information presented suggests that variations in physiological responses, as measured by $\dot{V}$O2 and HR calculations will differ, if indeed the tasks are not clearly simulated. Although comparison of cycling protocols were available, the data related primarily to M$\dot{V}$O2 and little emphasis was placed on the submaximal responses. There was some degree of uncertainty demonstrated with the use of HR as a method of equating work stress. The inconsistencies demonstrated in the literature suggests that this methodology can be modified by a number of factors, indicating the possibilities for errors in estimating from heart rate values.

Mechanical Responses in Cycling.

Force Kinetics during Cycling.

A definitive and useful method of measuring the external force that muscular action creates is made possible through the use of strain gauges. These devices are glued to structures of the bicycle, such as the crank or pedals. When these structures deform under pressure or force the gauges also deform. Interfaced with these gauges, measuring equipment provides the researcher with a continuous output of force or torque. Through this application of scientific instrumentation it becomes possible to determine exactly how a cyclist is applying force at a particular time during pedalling. This information may then be used to help discern the components of pedalling frequency (Faria, 1984).

The forces and moments exerted during cycling can be reliably and accurately measured either by strain gauges applied along the crank arms or measured by different types of strain gauges applied to the pedal (Ericson and Nisell, 1988). Valuable information pertaining to the performance characteristics while pedalling have been established from such studies. For many years it was thought that cyclists had a distinct advantage over their fellow competitors when using lock in type pedals, for it was believed that cyclist pull-up during the pedal cycle. Hoes et al. (1968) were one of the first group of researchers to speculate from their study that toe clips may not help the cyclist pull-up. It was stated that toe clips on the pedals are probably not used as much as it was first believed and that its use was most likely in effect during sprints or uphill climbs. Further study into this conclusion resulted in similar results by Davies and Hull (1983) and confirmed by research by MacLean and Lafortune (1988). In their study, MacLean and Lafortune used a purpose-built cycle ergometer with frame geometry identical to that used in contemporary road racing bicycles. The crank was equipped with a strain gauge in order to measure the component of force acting at right angles to the right hand bicycle crank. Specifically, their results indicated that the popular notion that cyclists pull-up in the recovery portion of the pedal stroke thereby producing positive torque throughout the pedal cycle was demonstrated to be untrue. Even when the subjects were given biomechanical feedback of their cycling patterns, it was noted that the negative torque was still present. However, trends for lower peak positive and negative torque, and reduced duration of negative torque were also displayed. The net effect was a decrease in the absolute workload required for the same task.

Lafortune et al. (1983) reported important differences in the pattern of force application on the pedals in a group of US National team cyclists. Force application and movement patterns of the top 6 male 4000m pursuit riders in the USA and the female 3000m world champion were studied during simulated all-out competitive rides of 4 min 45 secs. The cyclists rode a racing bicycle mounted on a road emulator. Data were collected online from both legs during 4 periods of the ride. Average power output ranged from 331 to 449 watts with cadence between 103 and 126 rpm. Lafortune et al. found that during the first 180 degrees of the pedalling cycle the riders were between 69 and 79 % effective in their force application. Right and Left asymmetries were found in total force applied, work done and pedal angle. The mean work asymmetry was found to be 4.3%.

The effective use of strain gauge represents a source of valuable information. MacLean and Lafortune (1988) have demonstrated the benefit of direct application of this information for training purposes. The value of strain gauge devices do also represent a source of information that can be exploited by exercise physiologists. As it is well known, the execution of a task like cycling requires the recruitment of a specific number of muscle groups. As the intensity of the task varies so does that number of motor units activated to perform the work change(Brooks and Fahey, 1984). As the activity continues the stress associated with the task stimulates the cardiopulmonary system by continuous neural input controlled by the sympathetic and parasympathetic processing systems (Brooks and Fahey, 1984). It is well documented that the stress associated with a given load is represented by an adjustment of the cardiovascular function, specifically HR and $\dot{V}$O2. This adjustment has been shown to be representative of a linear response with increasing workloads. Thus for the exercise physiologist, the use of strain gauge devices in combination with physiological information, as HR, under various load situations while cycling in the field can provide valuable information. This information could serve to document typical workload situations during training programs and competitive events.

Kustlinger et al. (1984) noted that force outputs can be correlated to measured work levels. They noted that up to 280 Watts, the mean peak force of all subjects was linearly correlated to workload, while a further increase of workload led to a curvilinear increase of peak force. They also noted that force as measured by strain gauges on the crank could be used to distinguish between elite cyclists and non-cyclists. When compared to the non-cyclist, elite cyclists showed peak values that were significantly lower at all levels of workload. The authors identified that lower peak values in the dynamic force records are accompanied by a lower $\dot{V}$O2 at the same workload level and a higher maximum workload in the exercise test. This indicated an improved mechanical efficiency. As such, it is evident that a process for describing physiological profiles of cyclists in the field exists and can offer practical information to exercise physiologist. Similarly, Croisant and Boileau (1984) identified the importance of obtaining such information. Their investigation concluded that the energy cost of bicycle ergometer work is not linearly related to the work output but rather depends on the rate and force with which the work is accomplished suggesting that identifying force patterns in cycling is an important parameter of analysis in the evaluation of physiological cost to work.

CHAPTER 3

METHODOLOGY.

Introduction.

The primary objective was to determine if the work loads indicated by HR on two laboratory ergometer tests are comparable to work loads performed at equal heart rates in the field. Work was represented both indirectly as oxygen consumption and directly by the measurement of rotational force measured in the crank (PCT and ACT_{60}) (this concept will be developed subsequently in this chapter).

The basic research design was to measure $\dot{V}O2$ max and lactate threshold using two methods of resisting pedal rotation (treadmill riding and race ergometer). This serves two purposes: 1) provided a basic comparison of physiological response to the two laboratory protocols; and 2) indicated the HR/$\dot{V}O2$ relationship relating to Lactate Threshold (LT) that can be used for extended rides in the field. Following these determinations, three, ten minute field rides were used at HR established as 10% $\dot{V}O2$ lower than, equal to and 10% greater than LT. Measurements of $\dot{V}O2$, PCT and ACT_{60} were made.

The Subjects.

The subject population was made up of male volunteers who were active cyclists and have had some competitive experience. The total number of subjects in this experiment was 8.

Subject Orientation.

Each subject was introduced to the laboratory prior to the actual laboratory investigation in order to provide them with the necessary information and an opportunity to try out the exercises at low intensity. Instruction and procedures for each of the test protocols was reviewed. Safety concerns were thoroughly discussed and once the subject had received all of the necessary information, they were asked to participate and sign a consent form which outlined all procedures and risks.

Procedure for Exercise.

Testing Protocol.

Testing required 4 laboratory sessions and one field session. The first two periods were necessary to determine the subject's maximal oxygen uptake ($\dot{V}O2$ maximum) on each of the two separate tasks: treadmill cycling (TC)and race ergometer cycling (RE). The information was subsequently used to establish the workload intensities for the subject's following visits. The remaining 3 testing periods were used to evaluate steady state response both in the field and laboratory settings. The field test was conducted at work rates equivalent too LT, LT - 10 % and LT + 10% (see appendix II). The cadence used for each work rate was reproduced to simulate corresponding work situations in the laboratory for all three tasks. Those workloads performed in the field were simulated in the laboratory.

A period of 48 hours was maintained between successive $M\dot{V}O2$ measures. For all steady state test periods a period of 24 hours was given between each task. However, all three work loads for a given task were performed in the same test period with a 20 minute rest period alloted between each load. All tests for a given subject were completed within a two week period in order to minimize the effects of training.

Measuring VO2 Maximum

The procedure to determine each subjects $\dot{V}$O2 maximum followed a continuous progressive work test protocol for all three cycling tasks. The subject was allowed to practice on the treadmill at 2% grade and 20 mph in order to determine the appropriate cadence and gearing which would allow a 30 to 60 min endurance training ride. This produced a sublactate threshold performance. The treadmill cycling test was performed on a standard racing bike at the same cadence and gearing established during the practice ride and progressed by increasing grade by 0.5% increments at one minute intervals from an initial grade of 2%. Velocity was maintained at 20 mph until maximum $\dot{V}$O2 had been achieved and then reduced for recovery riding.

The race ergometer $\dot{V}$O2 maximum tests followed comparable test procedures. (usually about 90 rpm) at an initial load equivalent to that load calculated for the treadmill test (see appendix G). Work increments for both RE and TC were similar. All calculations were made based on TC calculations so as to match the protocols in terms of the work stess produced by each condition.

Anaerobic-Lactate Threshold.

Micro samples of finger-tip blood were taken at the end of each work load during the RE max test and used in conjunction with Ventilation, $\dot{V}$O2, $\dot{V}$CO2, and ventilatory equivalents for O2 and CO2 ($\dot{V}/\dot{V}$O2, $\dot{V}/\dot{V}$CO2) to estimate thresholds for subsequent submaximal workload tests.

The Submaximal Work Test.

Measuring Steady State Loads in the Field.

The subject was required to ride a specially equipped race bike in the field at three work intensities LT - 10%$\dot{V}$O2, LT and LT + 10%$\dot{V}$O2 as determined from the maximal aerobic performance tests. Heart rate values were used as indicators for the work load intensity (Refer to appendix H for a complete description). Each work load was performed at a steady pace for a 10 minute interval. The cyclists were allowed to choose their own gear combination for the performance of each work load but were asked to use the same cadence (monitored on the bike by a cyclometer) used during the $\dot{V}$O2 max tests. Finger tip blood samples were taken at 1 and 3 minute post exercise.

Steady State Laboratory Test.

The subjects were required to perform three work intensities on each of the three tasks (RE and TC) similar to those work rates performed in the field (LT, LT-10%$\dot{V}$O2, LT+10%$\dot{V}$O2). The subjects were required to cycle at a constant rate for a period of 10 minutes. Pedal frequencies utilized in the field to complete each of the work loads were used in the completion of the laboratory tests. Proper work load settings (ie. treadmill speed, ergometer tension belt) were calculated using these field values for frequency (see appendix F and G for proper calculation procedures). Finger tip blood samples were taken at 1 and 3 min post exercise.

Equipment and Collection.

All testing and data collection were performed in the Department of Human Kinetics at the University of Ottawa. The treadmill cycling test was performed on a

Quinton treadmill equipped with a rubberized surface. Speed and gradient changes are manually adjusted. Maximum speed capability is 25 mph with a maximum gradient change of 40 degrees. The racing bike used for the TC protocol was a Grandis Italian racing bike equipped with adjustable Dura-Ace handle bars and Look lock-in pedals. The seat was adjustable both vertically and horizontally.

The race bike ergometer task was performed on a racing bike (Bridgestone) in which the gear chain was directly hooked up to the front wheel ring gear of a Monark ergometer. As such, it was possible to use the brake loading system of the Monark ergometer to control the workload. Both the mounted racing bike and Monark ergometer were mounted within a metal frame which allowed the two bikes to act as a single system. The handle bar and seat were both adjustable vertically and horizontally in order to allow precise measurement comparability with the racing bike. The pedals were equipped with Look lock-in pedals to allow the cyclist to use racing shoes.

For the TC and RE tasks, a specially build crank was installed in order to measure the force acting on the arm crank. The strain gauges were located at both the anterior and posterior sides of the crank arm (85 mm from axel origin) (see appendix D for specifications). Only the forces normal to the crank axis in the plane of crank rotation were recorded. It would have been necessary to measure forces in the other two planes in order to account for all the energy expended on the crank (ie: to account for rotational torque about the crank axis and for force parallel to the crank axis); however, this partial measurement of force, and the calculation of impulse and work to which it leads, were only used for comparative purposes between the field and three laboratory ergometer apparatus results. Thus, comparisons relating only to relative differences in the rotating force of the crank rather than to absolute differences between conditions were performed.

With respect to the analysis of the physiological responses for both the max and submax test protocols, HR was recorded by means of a wireless transmission device. The data collection in the heart rate microcomputer was then transferred directly by means of computer interfacing to a data analysis program developed by Polar Electro Finland (Appendix B).

Metabolic determination and gas analysis ($\dot{V}O2$) was undertaken by an open circuit method. The cyclist was hooked up to a two way non-rebreating, T-shaped valve which directed expired gas to an 8 L mixing box from which continuous sampling of O2 and CO2 was done. Similarly, inspiratory volumes were collected for the full testing period (see appendix C for more detailed information). Expired gases were also collected directly into a Collins chain compensated gasometer to verify calculations of oxygen consumption for the last 30 seconds of each work intensity.

Analysis.

The data collected for the submaximal cycling protocols during each 30 seconds of the 10 min constant work periods were analyzed. The mean values for HR, $\dot{V}$O2, PCT and ACT$_{60}$ for the 3 cycling tasks (FC, RE and TC) at each of the three workloads (LT, LT-10%$\dot{V}$O2, LT-10% $\dot{V}$O2) were analyzed using a one factor experiment with repeated measures.

The findings from these analytical procedures made it possible to determine if response patterns elicited at submaximal levels were comparable among the three experimental conditions. Specifically, it was possible to verify the reliability of HR as an indirect measure of absolute workloads during cycling.

The information derived from PCT and ACT$_{60}$ values made make it possible to determine if a constant relationship existed between the various physiological parameters at constant work rates. This knowledge provided the information required to assess the validity of measuring PCT and ACT$_{60}$ during cycling as a means of identifying work load thresholds directly in the field setting.

Appendix B

CARDIOVASCULAR ANALYSIS AND MONITORING PROCEDURE

HR was recorded by means of a wireless transmission device. This heart rate microcomputer allowed recording of HR for the full duration of all test protocols. The system offered a memory capacity which was sufficient to collect sample intervals of 5 seconds. The model used was a Sport Tester PE-3000 by Polar Electro Fitness Technology of Finland. The data collection in the heart rate microcomputer could then be transferred directly by means of computer connection to a data analysis program developed for this heart rate microcomputer by Polar Electro Finland.

Appendix C

METABOLIC ANALYSIS AND MONITORING PROCEDURES

An open circuit method was used for all laboratory task investigations. The cyclist respired via a two way non-rebreathing, Tshaped valve. Inspiratory volumes was recorded in a Morgan Ventilometer Mark 2. The collected gases entered into an 8 L mixing box from which about 0.6 l/min is passed through a tube containing calcium sulfate. At this point, analysis of O2 and CO2 is made directly by the Amtek S-3A Oxygen Analyzer and the Amtek CD-3A Carbon Dioxide Analyzer. Output from the gas analyzers and volume recorder was integrated with the Pulmonary Exercise System Software produced by S and M Instruments and Physiodyne Instrument. Data was analyzed and stored every 30 seconds. For purposes of verification, expired gases were collected directly into a Collins chain compensated gasometer in order to calculate oxygen consumption for the last 30 seconds of each work level.

Appendix D

DATA ACQUISITION SYSTEM FOR FORCE OUTPUT

(1) The specially built crank apparatus was used for all test protocols.

(2) The strain gauges were located on the anterior and posterior sides of the right crank arm, 85 mm from the axel origin (total length of crank arm = 170mm).

(3) The strain gauges are part of a modified wheatstone bridge.

(4) The crank system received the electrical signal (voltage signal) from the strain gauges (force output). The system had a voltage to frequency generator to prepare the signal for transmission.

(5) The force signal was then transmitted as an 80 to 90 KHz FM signal to an antenna placed around the crank axel of the crank arm.

(6) The force signals and angle were then prepared for recording by means of a modulating unit contained in a water bottle. The unit has a Time Base Generator system which prepared the signal for recording by arranging the signal on a basic timing track compatible for recording on tape.

(7) The force signal was received into this unit as an an 80 to 90 KHz FM signal and was reduced by a factor of 10 (ie. to 8 to 9 KHz) in order to make it compatible with commercially available recording apparatus.

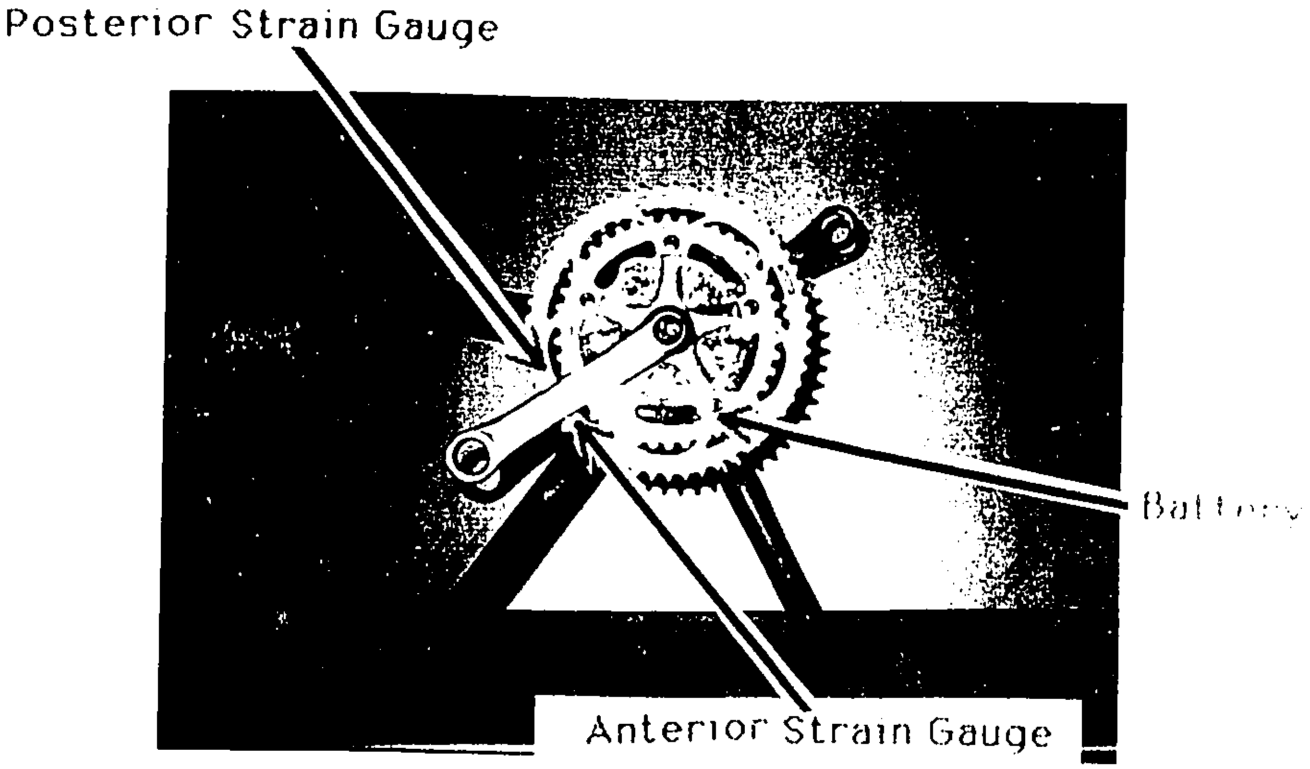
(8) These signals were then recorded by means of a portable tape recorder carried on the riders waist (Sony Walkman stereo cassette recorder Model WM-D3).

(9) The tape recorder records 1 channel of force and 1 channel of angle information.

(10) The information stored on tape could then be analyzed by means of a converter which re established the signals as analog voltages.

(11) A data acquisition system (Compaq model and hybrid software) then translated the signal to digital as the basis for statistical and graphical comparisons.

(12) A program which was developed specifically for these data filtered and measured each impulse or curve that had been recorded on an individual or cumulative basis.



Transferable Crank Apparatus

Appendix E

METHOD TO CALCULATE MAXIMUM AEROBIC POWER ($\dot{V}O2$ MAX)

Procedure:

The following sequence of events were followed for each subject with the option of altering initial workloads on an individual basis.

(1) Have subject sit on the bicycle and initiate memory on the HR monitor (PE3000).

(2) Appropriate settings are made for the initial workloads as described in appendix F and G.

(3) Subject should be on the mouthpiece prior to the onset of the test, allowing tissot tank to wash out residual tissot tank gas by having the expired air flow through the tank.

(4) Tissot tank thermometer, deflection scale, room thermometer, and barometer are monitored for each work load. $\dot{V}O_2$ is also determined at 30 sec intervals by a metabolic circuit (appendix C).

(5) Upon completion of workload, the subject is allowed to rest for at least five minutes (ie: to HR < 120 bpm) before attempting a supramaximal load (if deemed necessary by a lack of a plateau during the progressive test).

(6) $\dot{V}O2$ calculations conform to the basic formula: $\dot{V}O2 = (\dot{V}IxFIO2) - (\dot{V}ExFEO2)$

Appendix F

WORK LOAD CALCULATION FOR RACE ERGOMETER CYCLING

The submaximal work loads were calculated by the following equation:

$$\text{Power} = \text{Kg} \times 6 \text{ meters} \times \text{rpm}$$

where kg is the tension placed on free-wheeling fly wheel to increase the resistance associated with cycling, m is the distance in meters covered by bike in one full rotation of the pedal position from 0 degrees about a 360 degree radius; and rpm is the number of revolutions per minute.

Appendix G

WORK LOAD CALCULATION FOR TREADMILL CYCLING

For the treadmill cycling protocol, work was calculated based on the following equation:

$\text{Work}=(\text{weight}\cdot\text{velocity}\cdot\sin\theta)-(0.185\ \text{kp}\cdot\text{velocity})+(0.000434\ \text{kp}\cdot\text{min}\cdot\text{m}^{-1}\cdot v^{2})$

Where work was measured in kpm per minute, weight was that of the cyclist and his bike in kilograms, velocity was the speed of the treadmill in meters per minute, and θ was the angle of the treadmill bed. The first term of the above equation estimates the work required to maintain the cyclist's stationary position at a given grade and speed on the treadmill. The second term 0.185 kp· velocity, estimates the rolling friction created by viscous friction, it is a also function of the type of surface, the deformation of the tire, the type of tire, the tire pressure, and various bearings in the driving apparatus of the bicycle. The third term, $0.000434\ \text{kp}\cdot\text{min}\cdot\text{m}^{-1}\cdot\text{velocity}^{2}$, estimates the resistance created by surface friction; it is a function of the type of surface, the deformation of the tire, the type of tire, the tire pressure, and various bearings in the driving apparatus of the bicycle. A fourth term, which includes the cube of the velocity would be necessary if the cyclist was encountering wind resistance, however, this factor is unecessary in our equation since the cyclist is virtually motionless. It has been shown on two separate occasions (Hagberg et al., 1978; Hagberg et al., 1981) that the use of the above equation results in reliable and accurate predictions of power associated with known $\dot{V}O2$ consumption values.

Appendix II

TESTING PROCEDURE FOR FIELD EVALUATIONS

The following sequence of events was used for each subject.

Procedure:

(1) Work load and heart rate values were determined from the maximal aerobic performance test. These values were based on the determination of the Lactate Threshold (LT), LT - 10%$\dot{V}$O2 and LT +10%$\dot{V}$O2 (see example below).

(A)

where LT = 80% of $\dot{V}$O2 maximum,

LT-10%$\dot{V}$O2 = 70% of $\dot{V}$O2 maximum,

LT+10%$\dot{V}$O2 = 90% of $\dot{V}$O2 maximum.

(B)

80% of $\dot{V}$O2 maximum = 179 bpm.

70% of $\dot{V}$O2 maximum = 168 bpm.

90% of $\dot{V}$O2 maximum = 192 bpm.

(2) The subject sat on the bicycle and the HR monitor memory program was initiated.

(3) The subject cycled at his preferred gear ratio up to the desired HR and once this HR had been achieved within the first few minutes of the work load, the subject maintained this work rate by monitoring the heart rate monitor placed on the wrist (model PE3000 Sports Tester) until the 10 minute work span has expired.

(4) At 9 minutes and 30 seconds of the work load the subject switched the valve mechanism to initiate a 30 second collection interval.

(5) At the 10 minute mark of the work load the subject switched the valve to a closed position to ensure that the expired gases collected in the Douglas Bag were properly contained for analysis.

(6) The subject were then stopped and the collected gases were measured. A sample was retained for analysis by a metabolic circuit (O2 and CO2 analyses were made by the Amtek S-3A Oxygen Analyzer and the Amtek CD-3A Carbon Dioxide Analyzer).

(7) Using a volumetric reader (Cowan Parkinson Dry-Gas Meter measurement), the volume of expired gases collected for the 30 second period was determined, with compensation for the analysis sample which had been extracted.

(8) Ambient temperature and barometric pressure were recorded.

(9) The procedure was repeated for all other work loads with intervening 20 minute rest periods between each ride.

Appendix I

EQUIPMENT FOR FIELD TESTING

The following equipment was required for proper metabolic ($\dot{V}O2$), cardiovascular (HR) and mechanical (PCT and ACT$_{60}$) evaluation of steady state workloads in the field:

(1) A Douglas Bag (Warren E. Collins, Boston Mass.) was used for gas collection with a 100 Litre capacity.

(2) A Dry-Gas Volumetric analyzer (Cowan Parkinson Measurement) was used to measure volume of expired gases (Litres - L).

(3) Mylar balloon bags were used for the temporary storage of gas samples.

(4) Breathing apparatus (the type used in this study is a SCUBA type) and nose clip.

(5) Switching valve apparatus for controlling collection intervals. The valve used for the the study was a three-way system: an input connection (I), an output direct to the atmosphere (O1) and an output to Douglas bag (O2). Switching the valve circulates expired gases to O1 or O2 (see appendix S). Tube diameter was 0.04 m.

(6) Large laboratory spiral tubing for expired gases: 0.4 m length hose running from breathing apparatus to the (I), 1.0 m length hose running from (O2) collection output of switching valve unit to the Douglas bag.

(7) Rear bike support device to install wind deflector apparatus in which the Douglas bag was contained. The wind deflector served to protect the Douglas bag from the effects of the wind (see appendix T).

(8) Heart Rate monitor - model PE3000 - Sports Tester by Electro of Finland.

(9) Specially built crank device for force output.

(10) Solar cyclometer for the measurement of cadence (Cat Eye - model CC-2000).

Appendix J

RACE ERGOMETER CALIBRATION PROCEDURE

Calibration of the systems was completed to ensure that the resistance calculated in kg was equal to that value in kp (kilopounds). The procedure required that the tension belt be removed. A large volumetric flask was then placed on the existing spring and distilled water was added in increments of 0.05 kg to correlate kg values with kp values (note: 1 gram = 100 ml of H_2O).

Appendix K

CALIBRATION PROCEDURE FOR CRANK APPARATUS

The crank apparatus was calibrated by a static calibration procedure. The crank arm was placed at a 90 degree position to the horizontal. Sampling was done with the unloaded crank and when it was loaded by 10 lbs increments to a maximal loading of 120 lbs. The calibration factor was immediately calculated by the available software. Calibration procedures were followed prior to each test session.

The crank torque information was evaluated based on the defined calibration factor and the base line used for all calculations was designated for the purpose of this study as the average minimum point calculated for the sample period.

Appendix L

RAW DATA $\dot{V}O_2$

Table 10: Raw data $\dot{V}O_2$ - (ml·kg^{-1}·min^{-1})

	FC	RE	TC	FC	RE	TC	FC	RE	TC
	sub LT			LT			supra LT		
subject #									
1	41.3	46.1	49.5	47.6	51.6	55.6	53.4	59.4	58.2
2	36.3	42.0	41.2	45.3	45.4	54.4	53.1	54.4	56.0
3	52.5	55.5	49.9	61.3	61.7	56.7	70.7	61.9	59.6
4	38.1	45.4	51.1	47.8	55.4	54.4	60.1	59.2	58.1
5	30.7	48.0	47.2	46.8	50.5	48.8	59.5	57.5	56.7
6	29.8	48.7	50.4	43.0	57.0	55.4	54.4	62.5	60.5
7	39.3	45.5	47.8	47.9	46.1	51 8	64.2	52.1	56.6
8	46.3	47.4	47.9	45.9	51.1	52.4	53.0	54.6	60.5

Note: FC = field cycling RE = race ergometer cycling
TC = treadmill cycling

Appendix M

RAW DATA ACT$_{60}$

Table 11: Raw data ACT$_{60}$ - N·s

	FC	RE	TC	FC	RE	TC	FC	RE	TC
		sub LT			LT			supra LT	
subject #									
1	79	167	154	93	169	171	118	172	171
2	201	185	148	170	157	140	199	174	170
3	125	122	NA	132	130	NA	135	145	NA
4	164	126	156	176	172	157	140	174	161
5	227	104	140	199	117	133	218	144	174
6	217	161	161	251	168	162	159	166	164
7	178	179	182	164	181	175	216	188	182
8	221	160	172	183	160	196	220	164	178

Note: FC = field cycling RE = race ergometer cycling
TC = treadmill cycling

Appendix N

RAW DATA PCT

Table 12: Raw data PCT - (N)

subject #	FC	RE	TC	FC	RE	TC	FC	RE	TC
	sub LT			LT			supra LT		
1	185	428	389	230	450	447	301	432	465
2	471	453	354	403	382	334	491	403	403
3	339	361	NA	370	406	NA	394	457	NA
4	397	327	371	440	397	384	353	408	418
5	580	394	333	504	316	298	581	351	392
6	427	381	380	495	414	391	415	428	427
7	440	430	404	391	444	403	511	538	436
8	500	404	421	472	419	476	523	436	450

Note: FC = field cycling RE = race ergometer cycling
TC = treadmill cycling

Appendix O

FIELD AND LABORATORY TEMPERATURE DATA

Table 13: Temperature Data

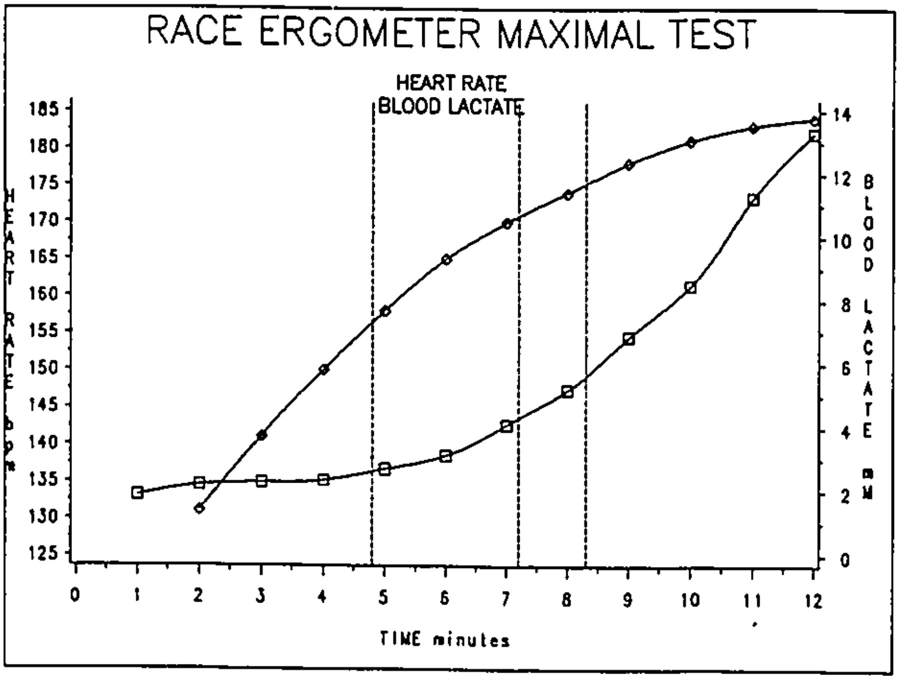
	Field Cycling	Race Ergometer	Treadmill Cycling
1			
Temp	18.0	23.0	23.0
BP	765.5	739.6	745.1
2			
Temp	29.0	23.0	23.0
BP	765.5	739.7	742.3
3			
Temp	22.5	23.0	23.0
BP	754.0	750.5	743.79
4			
Temp	11.0	23.0	20.0
BP	753.0	743.7	734.2
5			
Temp	12.0	21.5	23.0
BP	758.0	745.87	747.2
6			
Temp	7.0	20.0	24.0
BP	756.0	751.1	742.7
7			
Temp	15.0	20.0	19.0
BP	749.0	751.1	748.4
8			
Temp	7.0	20.5	20.5
BP	745.5	757.3	741.83

Note: Temp = ambient temperature - degrees celsius(°C)
BP = barometric pressure (station pressure) in mmHg

Appendix P

LACTATE THRESHOLD CURVE - SAMPLE CALCULATION

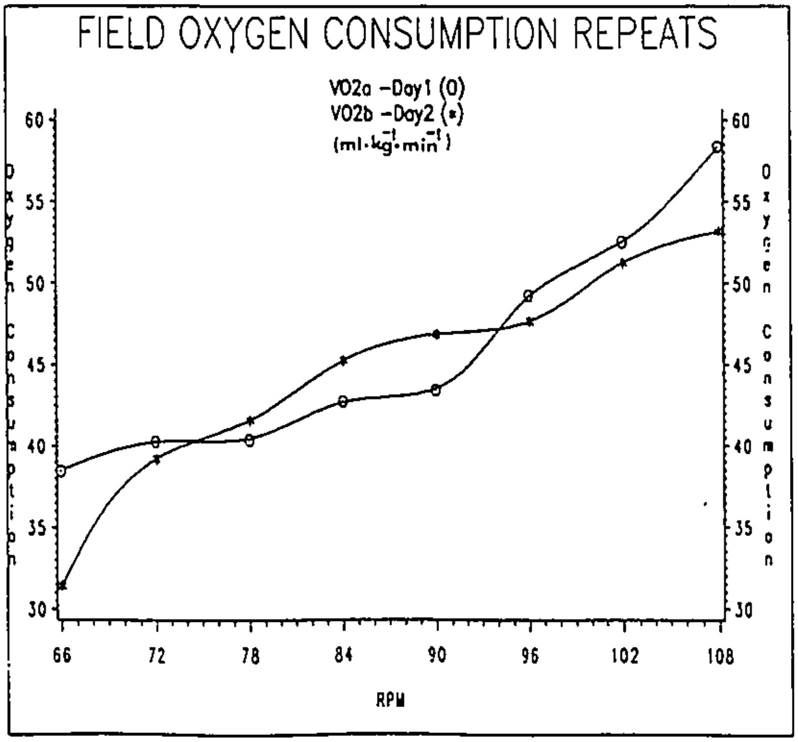
The following figure demonstrates the basic methodology used for describing the 3 work intensities for use during this study. Lactate values during a progressive work test were utilized to define the Lactate threshold as described on page **80** and appendix **H**. The 3 work intensities indicated below by the 3 vertical lines are representative of workloads equal to LT-10%$\dot{V}O_2$(a), LT(b) and LT+10%$\dot{V}O_2$(c).



Appendix Q

V̇O2 REPEAT MEASUREMENTS - PILOT STUDY DATA

The following figure represents repeated measures of V̇O2 taken in the field. The system utilized was the same system of collection described for use in this study (appendix I). A discontinuous incremental work test was followed were the subject was required to remain at a given gear ratio and increase cadence in order to increase the workload. The figure demonstrates consistency of measure showing the reliability of the system during different collection periods. The variations seen are reflective of the changes in wind conditions and temperature observed over the different test periods.



Appendix R

CONSENT FORM

Informed Consent Letter

I ______________________________, understand that the purpose of this research project is to investigate the physiological responses associated with cycling on three seperate cycling conditions at submaximal and maximal workloads and authorize the Department of Kinanthropology at the University of Ottawa to administer and conduct these exercise tests, under the direction of Glen Kenny.

I also understand that the term submaximal work applies to this research project as; cycling for each of the three cycling conditions, treadmill cycling (TC), stationary race bike ergometer (RE) and field cycling (FC) at three different workloads equivalent to LT-10%$\dot{V}O2$, LT and LT+10%$\dot{V}O2$ at which I will cycle for a period of 10 minutes at each of these workloads and then I will be given a 20 minute rest period before the next workload is performed. As well, I understand that the term maximal work will apply in this study to, the act of riding for two cycling conditions (TC, RE) up to a point of full physical exertion induced by a progressive increase in the work performed over time. I understand that it is likely that I will experience some local muscular fatique, dryness of the mouth and throat, and an increased resistance to breathing; although every effort will be made to conduct the test in such a way as to minimize discomfort and risk. However, I understand that just as with other types of diagnostic tests there are potential risks associated with an exercise test. These include episodes of transient lightheadedness, fainting, chest discomfort, leg cramps and very rarely, heart attacks. I recognize that a medical examination prior to performing exercise testing is advisable.

I have agreed to perform both the submaximal and maximal cycling test on the treadmill with the provision that at least 2 spotters will be watching me through the full extent of the test period. I agree to allow the researcher to place a PE3000 heart rate monitor and transmitter unit on me. As well I agree to allow the researcher to place me on a two-way non-rebreathing, T-shaped valve so as to allow for gas collection and analysis. I also agree to allow capillary blood samples to be drawn by micropuncture from a finger-tip during the maximal race egometer cycling as well as following each workload episode on the RE, TC and FC conditions and realize that I may experience a slight pricking sensation when blood samples are collected.

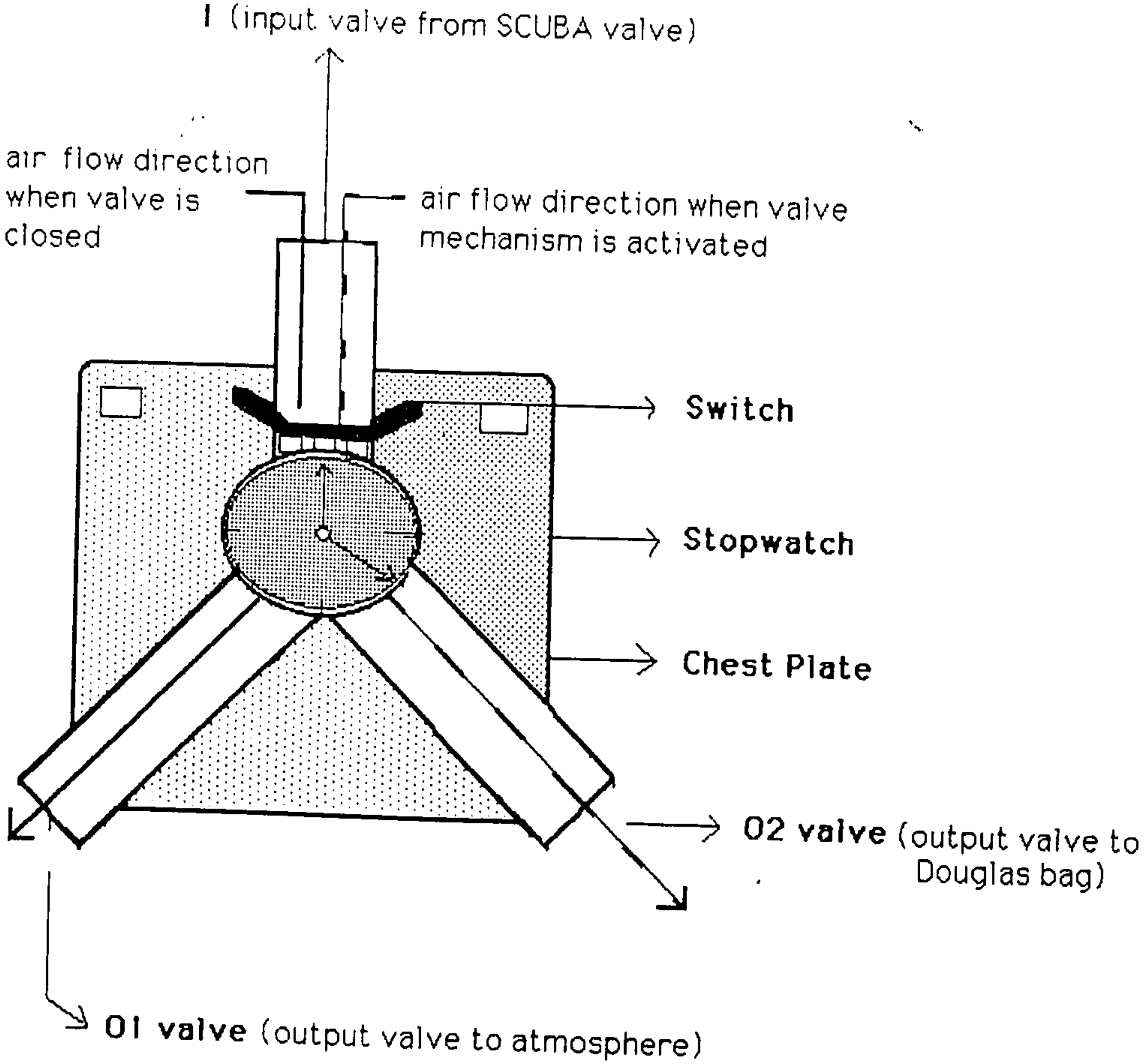
Finally I agree that I will be asked to perform to the best of my ability. Yet I fully realize that I reserve the right to discontinue my activities as a subject at any time during this entire research project. As well I understand that the results of my performance will remain in the strictest confidence between the researcher and myself.

Signature of subject:________________________

Witness:____________________Date:_____________

Appendix S

SWITCH VALVE SYSTEM



Appendix T

OXYGEN COLLECTION SYSTEM IN THE FIELD