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**Triathletes: A physiological characterization. The contribution
of selected physiological variables in the discrimination of
triathlon performance**

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San Jose State University, 1989

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TRIATHLETES: A PHYSIOLOGICAL CHARACTERIZATION

The contribution of selected physiological variables
in the discrimination of triathlon performance

A Thesis

Presented to

The Faculty of the Department of Human Performance
San Jose State University

In Partial Fulfillment
of the Requirements for the Degree
Masters of Arts

By

Carla M. Phillips

August, 1989

APPROVED FOR THE DEPARTMENT OF HUMAN PERFORMANCE

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ABSTRACT

TRIATHLETES: A PHYSIOLOGICAL CHARACTERIZATION

The contribution of selected physiological variables in
the discrimination of triathlon performance

by C. M. Phillips

Forty-three male triathletes were studied to determine

the physiological determinants of triathlon performance. Physiological measurements included maximal oxygen uptake, ventilatory threshold, and anaerobic indices measured by arm-leg ergometry; leg, shoulder, and arm strength; body weight; relative fat; lean body weight; fat weight; linearity - fatness rating; and muscularity rating. Discriminant analysis identified two functions best described as an aerobic-body composition/size function and an anaerobic-strength/muscularity function, which respectively accounted for 78% and 22% of the variance in triathlon performance and correctly classified 65% of the triathletes. Multiple regression analysis revealed that the physiological variables collectively accounted for 62% of the variance in triathlon performance time with relative fat, leg strength, and maximal oxygen uptake as the significant variables. In conclusion, it appears that high aerobic capacity, greater leg strength, and a low percentage of body fat contribute to better performance in

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CHAPTER I

Introduction

This chapter is divided up into several sections as follows: background for the study, statement of the purpose, research hypothesis, delimitations, limitations, operational definitions, significance of the problem, statistical analysis, and summary.

Background for the Study

There is an inherent competitive spirit in most human beings. Whether it is between siblings, classmates, or professional athletes, the need to be "number one" exists to some extent in all of us. Out of this inbred rivalry has grown the need for many athletes to constantly seek new challenges. No longer is the marathon or the century bike ride enough. These athletes who need the extra challenge have brought about the formation of a new sport called the triathlon. It began as the Hawaii Ironman Triathlon in 1978 and has experienced such a great rise in popularity that it is now recognized as an independent discipline (van Rensburg, Kielblock, & van der Linde, 1986). Triathlon competitions now exist at all levels, from mini-triathlons to the ultimate Ironman. The

triathlon is a continuous event consisting of three different endurance activities combined into one. Triathletes therefore have to possess not only the skills to run, bike, and swim, but also the endurance to link the three events into one continuous event. Physiological profiles allow for the analysis of a sport's physical requirements as well as an athlete's potential for success (Wilmore, 1979). Profiles have been established for elite athletes in most sports, ranging from running and bicycling to volleyball and kayaking (Svedenhag & Sjodin, 1985; Johnson et al., 1985; Fleck, Case, Puhl, & Van Handle, 1983; Tesch, 1983). With the use of these profiles or characterizations, the relative importance of the variables that influence an athlete's performance in a sport can be determined (Nicholas, 1984). Once profiles have been completed on a large number of athletes from a given sport, an average or range can be established for any given level of performance (Nicholas, 1984). These requirements can then be used to monitor and adjust a training regimen for each athlete (Ready, 1984).

Physiological profiles have been done on athletes from all three components of the triathlon: running, bicycling, and swimming (Wells, Hecht, & Krahenbuhl, 1981; Pate, Barnes, & Miller, 1985; Johnson et al., 1985; Dwyer,

1983; Price, Byrd, & Stone, 1983). However, the demands placed on the triathlete, who combines all three of these sports into one continuous event, have not yet been thoroughly assessed (van Rensburg et al., 1986).

Since a physiological profile is necessary to determine the physical requirements of a sport, triathletes need to be among those athletes assessed. The physical

[REDACTED]

can not be expected to apply when assessing the physiological capabilities of an athlete who combines all three elements into one competition.

The current research on triathlete characterization is in its beginning stages, and presently consists of five journal articles (Rogers, Goodman, Mitchell, & Hattingh, 1986; van Rensburg et al., 1986; Holly, Barnard, Rosenthal, Applegate, & Pritikin, 1986; Kohrt, Morgan, Bates, & Skinner, 1987; O'Toole, Hiller, Crosby, & Douglas, 1987) and eight abstracts (Albrecht, Foster, Dickinson, &

& Massimino, 1986). The researchers in these studies have looked at many attributes of the triathlete, from blood analysis and aerobic capacity to training patterns. There does not appear to be any published research, however, that has examined the relationship between various physiological variables and the skill levels of triathletes.

Statement of the Purpose

The purpose of this study was to determine:

(1) the relationship between selected physiological variables and skill level (i.e., highly-skilled (HiS), average-skilled (AvS), and lesser-skilled (LeS)) in a triathlon competition and (2) the relative contribution of each variable to the prediction of performance time.

Approach to the Problem

Forty-three male triathletes were used to assess the following physiological variables: maximum oxygen uptake (VO_{2max}), ventilatory threshold (VT), anaerobic capacity (AC), anaerobic power (AP), fatigue index (FI), leg strength (LS), shoulder strength (SS), arm strength (AS), body weight (BW), relative fat (RF), lean body weight (LBW), fat weight (FW), and body somatotype (X & Y). Skill

level was determined by performance time in a triathlon (1.5-km swim, 45-km bike, 11-km run) as follows: the top third (approximately 33 1/3%) will be classified as HiS, the middle third as AvS, and the bottom third as LeS.

Null Hypotheses

1. There will be no significant difference between the HiS, AvS, and LeS triathletes on the basis of select physiological variables.
2. The physiological variables will not distinguish between triathletes as to their performance capabilities.
3. There will be no significant intercorrelations between the physiological variables.
4. The physiological variables will not be significantly related to triathlon performance time.

Delimitations

This study was delimited to 43 healthy male volunteers ranging in age from 18 to 45 years who all completed the 1987 USTS Bud Light Triathlon held on August 30, 1987 in San Jose, California.

Limitations

The factors in this study which could not be controlled included:

1. Level of training before the study began.
2. Nutritional content of the subject's diet.
3. Honesty of the subjects when reporting training schedules.
4. Genetic make-up of the subjects.
5. The investigators inability to control the effects of training/detraining on results of physiological tests.

Assumptions

1. There was no change in the physiological variables measured during the time elapsed between the laboratory testing and performance in the triathlon.
2. All subjects gave best effort performances both in the laboratory and during the triathlon performance.

Operational Definitions

The following definitions are given for terms used in this study.

Anaerobic Capacity (AC). Anaerobic capacity encompasses the glycolytic (lactic) component as well as the alactic component of energy release (Tharp et al., 1985). It is expressed in total work/time (kgm/30 sec) as defined by the following formula: $0.060 \text{ kg resistance legs} + 0.050 \text{ kg resistance arms} \times \text{kg of body weight} \times 6\text{m} \times \text{number of revolutions of flywheel in 30-sec period}$ (Bar-Or, 1978; Tharp et al., 1985).

Anaerobic Power (AP). Anaerobic power is the alactic phosphogen portion of anaerobic energy release (Tharp et al., 1985). It is calculated as the highest work performed during any 5-sec period (kgm/5 sec) from the following formula: $0.060 \text{ kg resistance legs} + 0.050 \text{ kg resistance arms} \times \text{kg of body weight} \times 6\text{m} \times \text{the highest number of revolutions of the flywheel in a 5-sec period}$ (Bar-Or, 1978; Tharp et al., 1985).

Body Density (Db). Body density is the weight of the body per unit of size (kg/l) and is calculated with the following formula: $\text{body density} = \text{body weight} / \text{body volume}$ (Fox & Mathews, 1981).

Body Somatotype (X & Y). Body somatotype as defined by the variables X & Y is a coordinate grid superimposed over a somatochart. Individual coordinate plotting points can be obtained by the following formulas: $X = \text{ectomorphy} - \text{endomorphy}$, and $Y = 2(\text{mesomorphy}) - (\text{endomorphy} + \text{ectomorphy})$. Variable X is a descriptive measure of linearity - fatness and variable Y is a descriptive measure of muscularity (Ross & Wilson, 1973).

Body Volume (BV). Body volume is the size of the body expressed in liters calculated from the following formula: $\text{body volume} = ((\text{body weight} - \text{true underwater weight}) / \text{water density}) - \text{residual lung volume}$ (Fox & Mathews, 1981).

Body Weight (BW). Body weight is the total weight of all body tissues expressed in kilograms (kg) (Cisar, 1986).

Densitometry. The process of estimating body fat based on the density of muscle, bone and adipose tissue with hydrostatic weighing (Brooks & Fahey, 1984).

Elite Triathlete. A triathlete who finishes in the top 10 to 15 finishers of a major triathlon (e.g., Hawaii Ironman Triathlon) (Holly et al., 1986).

Fat Weight (FW). Fat weight reflects the kg of body weight consisting of adipose tissue other than essential

fat (Brozek et al., 1963). It is calculated by the following formula: fat weight = body weight x relative fat.

Fatigue Index (FI). Fatigue index indicates the oxidative capacity of the muscles expressed as a percentage of peak power. It is calculated as the highest 5 sec power minus the lowest 5 sec power, divided by the highest 5 sec power multiplied by 100 (Bar-Or, 1983).

Lean Body Weight (LBW). Lean body weight is the kg of body weight that consists of lean tissues plus essential fat (Brozek et al., 1963). The formula is: lean body weight = body weight - fat weight.

Leg Strength, Shoulder Strength, and Arm Strength (LS, SS, & AS). Leg and arm strength are the peak torque values in ft-lbs for the dominant leg, forearm, and shoulder extension movements at 180 degrees/sec (Isolated-Joint Testing & Exercise, 1983).

Maximal Oxygen Uptake (VO₂max). Maximal oxygen uptake is the maximum rate at which an individual can consume oxygen (l/min). In this study VO₂ max was determined when two of the following three conditions existed (1) a heart rate within 10 beats per minute (bpm) of age predicted maximum, (2) respiratory quotient of 1.0 or more, and/or (3) a plateau or decrease in the subject's oxygen uptake with increasing workloads (Fox & Mathews, 1981).

Profile/Characterization. A profile is a gathering of information about the physical attributes of athletes (Nicholas, 1984).

Relative Fat (RF). Relative fat is the portion of the body's total weight consisting of adipose tissue calculated from the following formula: relative fat = $((4.57/Db) - 4.142) \times 100$ (Brozek et al., 1963).

Residual Lung Volume (RLV). Residual lung volume is the volume of air left in the lungs after a maximal expiration by the subject. This volume must be taken into account when measuring body composition by hydrostatic weighing (Pollock & Wilmore, 1984).

Respiratory Quotient (RQ). The ratio of carbon dioxide (CO₂) volume produced over the oxygen (VO₂) volume consumed. An RQ of 1.0 means that pure carbohydrate is being burned as fuel and the subject is near maximal oxygen uptake (Brooks & Fahey, 1984).

Triathlon/Triathlete. A continuous event (and the athlete who competes in one) comprised of three different activities. There is no standard distance, but the standard components are usually running, swimming, and bicycling (van Rensburg et al., 1986).

Ventilatory Threshold (VT). Ventilatory threshold is the onset of metabolic acidosis (anaerobic metabolism) as identified by the oxygen uptake curve (l/min) at the

point where at least two of the following occur: a nonlinear increase in ventilation (VE), a nonlinear increase in carbon dioxide production (VC02), an increase in end-tidal oxygen (Fe02) without a corresponding decrease in end-tidal carbon dioxide (FeC02), or an increase in RQ (VC02/V02) with increasing workloads of an incremental test (Wasserman, Whipp, Koyal, & Beaver, 1973).

Significance of the Problem

The triathlon has risen in popularity very rapidly over the past few years (Holly et al, 1986). As with most new sports, there is a need for some standard level of performance for which both elite and beginning athletes can strive. With this baseline data for a standard of measure, new participants in a triathlon competition will be able to judge if they have the necessary qualities to excel in the sport. This study attempted to differentiate between HiS, AvS, and LeS triathletes on the basis of selected physiological variables.

Statistical Analysis

Descriptive statistics ($\bar{M} \pm \bar{SD}$) were used to describe the physiological characteristics of the subjects and Pearson product-moment correlations were used to

determine if significant intercorrelations existed between the physiological characteristics. To determine which physiological variables discriminated between skill levels of triathletes (i.e. to classify triathletes as HiS, AvS, or LeS) a multiple discriminant analysis was used.

One-way analysis of variance and Tukey post-hoc tests were administered to see if HiS, AvS, and LeS triathletes differed significantly on the physiological variables.

Full-model and stepwise multiple regression analysis were used to determine if the physiological variables were significantly related to triathlon performance time. The SPSSX (SPSSX User's Guide, 1983) computer programs were used for statistical analysis of the data.

CHAPTER II

REVIEW OF LITERATURE

Introduction

Research has been done for over 20 years on the aerobic capacity of runners, swimmers, and cyclists. There have also been numerous profiles done on the athletes from these three sports. However, because of the newness of the triathlon as a sport, the research on these endurance athletes is still in its' beginning stages.

Holly et al. (1986) and O'Toole et al. (1987) examined the physiological characteristics of elite triathletes at the Ironman competition. Their results can only be applied to the population they studied: elite triathletes. The increase in popularity of the triathlon competition has attracted a large population of non-elite athletes. There is also a need to assess the characteristics of these athletes for the benefits of training future triathletes.

This chapter will focus on physiological characteristics and determinants of performance, aerobic work capacity tests, and discriminant analyses as they apply to swimmers, cyclists, runners, and triathletes.

Physiological Characteristics and Determinants of Performance

Methods used to assess physiological characteristics in research studies vary a great deal from sport to sport. Early research looked mainly at male or female athletes from single sports (Katch, 1974; Wilmore & Brown, 1974; Vrijens, Pannier, & Bouckaert, 1982). Then comparisons were made between male and female participants in the same sport (Wells et al., 1981; Ready, 1984; Pate et al., 1985), as well as between athletes from different sports (Saltin & Astrand, 1967; Zauner, Fencel, & Swenson, 1974). With the emergence of the triathlon as a separate sport there is a need to assess these unique athletes who compete in three events per race.

Swimmers

In 1983 Dwyer examined the physiological characteristics of three marathon swimmers (2 female and 1 male). He was attempting to identify those factors which might contribute to speed and success in marathon swimming. The subjects had a mean age of 19 years, a mean height of 164.5 cm, and a mean weight of 66.0 kg. Body composition was measured by underwater weighing and oxygen consumption was assessed by open circuit calorimetry while walking on a treadmill. $\dot{V}O_{2max}$ and AT were estimated from the oxygen

uptake test and revealed values of 4.20 l/min and 1.88 l/min, respectively. The female swimmers had nearly 30% relative fat, while the male swimmer had only 21.9%. These high relative fat values, when compared to swimmers who compete over short distances in a pool, are necessary for buoyancy and thermoregulation. In conclusion, the author stated that a high relative fat is the predominant physical feature of marathon swimmers, whereas high mechanical efficiency and the ability to sustain a high percentage of $\dot{V}O_{2\max}$ are also necessary.

Price, et al. (1983) examined selected cardiovascular, respiratory, power, strength, and body composition variables of eighteen competitive female swimmers ($\bar{M}$ age = 19.5 yr, $\bar{M}$ height = 168 cm) and nineteen control subjects ($\bar{M}$ age = 19.8 yr, $\bar{M}$ height = 164 cm). All subjects were tested pre-season and three times during the competitive season. Lung capacities, isometric arm flexion, vertical jump, body weight, a graded arm-crank ergometer test, and underwater weight were measured. The experimental group trained by running, weight training, stretching, and completing their regular swim workouts. During mid-season the running was phased out, and weight training was eliminated in late season. Arm strength was significantly greater in the experimental group, but leg

and hip power declined, possibly due to the emphasis on endurance exercise at the beginning of the training program. Body fat remained relatively constant in the control group ($\bar{M} = 25.2\%$) but declined throughout with the experimental subjects. This fat loss was compensated for by increases in lean body mass, as body weight did not change. Overall the tapering aspects of this program were found to be a valid training method, in that 17 of the 18 swimmers swam their best time of the season at the culminating meet.

Vaccaro, Ostrove, Vandervelden, Goldfarb, and Clarke (1984) assessed the body composition and physiological responses of 87 female masters swimmers (aged 20 to 69 yr). The subjects were divided into two groups: highly-trained (HT) and non-highly trained (non-HT) based on the frequency, duration, and intensity of their workouts. The highly trained swimmers worked out at a mean of 75% HRmax, and the non-highly trained swimmers at 55% HRmax. Body composition was determined by underwater weighing with correction for residual lung volume. Cardiovascular endurance was measured on a treadmill utilizing the Bruce protocol. Significant differences ($p < 0.05$) were found when comparing the HT and non-HT subjects on measures of body weight (58.4 vs. 64.4 kg), body density (1.049 vs.

1.037 g/ml), relative fat (21.2 vs. 26.3%), and lean body weight (45.3 vs. 46.8 kg). Significant differences favoring the HT group were also found in comparisons of VEmax (74.2 vs. 61.4 l/min), VO₂max (2.17 vs. 1.76 l/min), VO₂max (38.5 vs. 27.3 ml/kg/min), VO₂max (48.9 vs. 37.1 ml/kgLBW/min), O₂ pulse (0.23 vs. 0.13 ml/kg/beat), and O₂ pulse (0.29 vs. 0.22 ml/kgLBW). Both the HT and non-HT masters swimmers had lower relative fat values than previously reported data on untrained women.

Bicyclists

Perez (1979) looked at indices of maximal performance in the competitive junior cyclist. He compared twelve members of the 1977 American Junior cycling team to sixteen adult cyclists who had been competing in national and international competitions. Pulmonary function, maximal oxygen uptake, and body density from hydrostatic weighing were measured on all of the subjects. The adolescent cyclists showed significant differences in absolute weight (70.6 kg) and lean body weight (62.5 kg) when compared to the adult cyclists (66.5 kg and 58.6 kg, respectively) but no difference was obtained for percent fat (both were 11.7%). When compared to the mature cyclists the younger athletes showed no significant differences in VO₂max (65.2 vs. 65.9 ml/kg/min), but when looked at in absolute

terms a significant difference was found in mean VO_2max (4.28 vs. 4.63 l/min). It was concluded that there appears to be no substantial difference between the trained adult cyclist ($\bar{M}$ age = 24.1 yr) and the trained adolescent cyclist ($\bar{M}$ age = 17.2 yr) on the parameters measured in this study.

Physiological profiles of national class American cyclists was the topic of a study by Hagberg, Mullin, Bahrke, and Limburg (1979). Nine national class American cyclists with a mean age of 25.1 yr, mean height of 180.3 cm, and a mean weight of 72.0 kg participated in the study. Relative fat was measured by skinfold calipers and a mean of 7.6% was obtained. Maximal oxygen uptake was assessed on a bicycle ergometer eliciting a mean value of 70.3 ml/kg/min (5.71 l/min). The authors also measured maximal power output which was defined as the length of time the subject could maintain a total power output in excess of 3150 kpm/min. The mean value for this test was 52.8 seconds. The authors summarized by stating that the American cyclists' VO_2max values were essentially the same as top Europeans, who consistently perform better than the American athletes in competition. Therefore, other factors must contribute to producing high-level cycling performances.

Vrijens et al. (1982) sought to derive somatic and physiological age norms for Belgian road cyclists. Subjects for the study were 406 road cyclists ranging in age from 13 to 26 yr, who were divided into groups by age. Anthropometric measurements included body weight, height, and relative fat. Mean values for the older group, which was most similar in age to the subjects in this study, were age = 26.4 yr, height = 175.2 cm, and relative fat = 11.6%. Isometric strength of the lower extremities (extensors and flexors) was measured as well as performance during a continuous graded exercise test on a bicycle ergometer. Aerobic-anaerobic threshold was measured in 134 of the cyclists during the exercise test. The correlation coefficient between body weight and aerobic capacity was .746 in the 13 to 14 yr olds, .682 in the 15 to 16 yr olds, .687 in the 17 to 18 yr olds, and .343 in the 19 to 21 yr olds. In the older age groups the relationship between body dimensions and aerobic power was less pronounced (and also not reported), with genetic ability and endurance training becoming more important. The authors came to the following conclusions: a) the adolescent cyclist has a very similar profile to adult cyclists in vital capacity, heart volume, physical working capacity, and VO_2max , and b) endurance capacity (watts at a heart rate of 170 bpm) seems

to be of a greater importance than VO_2max in competitive cyclists since it was a better discriminator between elite and average performers.

Runners

Katch and Henry (1972) studied the relationship between estimates of maximal oxygen debt (max O₂ debt) aerobic power (VO_2max), 100-yard sprint time, and two-mile run times in 35 male college students ($\bar{M}$ age = 21.4 yr). The mean maximal oxygen debt was 4.89 liters net, the mean VO_2max was 3.34 l/min, the mean two-mile run time 13.73 min, and the mean 100-yard sprint time was 12.4 sec. The correlation between two-mile run time and max O₂ debt was .31, and between two-mile run time and VO_2max was .55. The multiple correlation for prediction of running performance was .57 using VO_2max and max O₂ debt. Adding the body weight variable to this only increased the correlation slightly ($\bar{R}$ = .58). Correlations for the 100-yard sprint performance were $-.01$ with maximal oxygen debt and $-.10$ with VO_2max ; the addition of the body weight variable increased the latter relationship to .20. The authors concluded that high predictions of individual differences in two-mile run and 100-yard sprint performances require more than the measures of maximal oxygen debt and maximal aerobic power.

Bransford and Howley (1977) compared four groups of subjects on the oxygen cost of running as it relates to speed of running. The groups were: trained male distance runners, trained female distance runners, and untrained but active males and females. The 40 subjects ($\bar{M}$ age = 21.85 yr) were measured for weight, height, and sum of six skinfolds (triceps, chest, scapula, supra-iliac, abdominal, and anterior thigh). Each subject underwent a series of treadmill tests to measure $\dot{V}O_2$ at submaximal and maximal loads. The trained runners had lower body weights, lower sums of skinfolds, higher $\dot{V}O_{2\max}$ values, and lower $\dot{V}O_2$ costs (economy) at any measured speed. A linear relationship between $\dot{V}O_2$ and speed of treadmill running was supported by this study, which held true regardless of gender or whether the subject was trained or untrained.

Wells et al. (1981) examined the physical characteristics, body composition, pulmonary function, and aerobic capabilities of male marathon runners ($\bar{M}$ age males = 30.9 yr). Seven males who trained 37 to 120 miles per week were tested two weeks prior to completing the Fiesta Bowl Marathon in Scottsdale, Arizona. Regression equations using running speed (predictor) and $\dot{V}O_2$ (criterion) were used to estimate oxygen utilization during the marathon run. Individual correlation coefficients

ranged from .989 to .999 with a mean of .996. The male subjects were classified as ectomesomorphic. The subjects had large vital capacities (5.4 liters) and a low relative fat (7.3 %). The mean VO2max value for the subjects was 59.2 ml/kg/min.

Hagan, Smith, and Gettman (1981) examined the relationship of marathon performance time (MPT) with VO2max, body composition, and training factors recorded for 9 weeks prior to the running of a marathon. Fifty male subjects ranging in age from 21 to 61 yrs (M = 36 yrs)

concluded that a high maximal aerobic power, low body mass, daily workouts, and training runs of long duration and distance contribute to better performance in a marathon.

Bulbulian, Wilcox, and Darabos (1986) studied the role of anaerobic factors in distance running performance. Twelve highly trained male cross-country runners with a mean body weight of 63.0 kg participated in the study. Maximal oxygen uptake ($\text{VO}_{2\text{max}}$) and running economy (ml/kg) were measured during treadmill exercise. Ventilatory threshold was determined and verified using VE, the ventilatory equivalent of oxygen (VE/VO_2), the ventilatory equivalent of carbon dioxide (VE/VCO_2), VCO_2 , and FeCO_2 . Anaerobic tests included the Margaria power test and the Monod critical power test to determine anaerobic work capacity (AWC). The data was used to predict performance time in a 8.05-km cross-country race. Subjects were found to be homogenous with regard to mean $\text{VO}_{2\text{max}}$ (72.1 ml/kg/min), ventilatory threshold (83.9%), and running economy at 241 and 295 m/min., as well as 8.05-km run time. The subjects were found to be heterogenous however, with respect to anaerobic capacity. The authors concluded that the non-invasive measures used in this study do not support the use of running economy or any one laboratory measure alone in predicting distance running success.

Housh, Thorland, Johnson, Hughes, and Cisar (1986)

sought to determine the association between selected body composition/body build variables and two-mile run performance and to determine the relative contribution of each variable to the model predicting two-mile run time. They took 39 adult males ranging in age from 18 to 33 years ($\bar{M}$ = 23.3 yr) who ran between zero and 75 miles per week, for the previous zero to 14 years. Five body composition/build variables were measured: height ($\bar{M}$ = 178.0 cm), body weight ($\bar{M}$ = 71.5 kg), relative fat ($\bar{M}$ = 12.3%), fat-free body weight/height, and 1/3 Ponderal Index Ht/BW. The authors found many significant relationships but only the BW with FFB/Ht (r = .89) had a shared variance above 50% (79%). The other correlations showed relationships from r = .01 to r = .58 among the variables. The model using body composition and body build variables as predictors of two-mile run time resulted in a multiple correlation of R = .65 accounting for 42% of the variance in two-mile run time. Body weight was found to be the strongest variable in the model for prediction of two-mile run time. It was concluded that in combination, body composition and body build variables explain, to a moderate degree, variance in two-mile run times.

Housh, Thorland, Johnson, Hughes, and Cisar (1988) also examined the association between selected

physiological variables and middle-distance running performance on a group of 39 adult males ($\bar{M}$ age = 23.3 yr). Maximal oxygen uptake, VT, running economy (RE), AC, LS, FW, and fat-free body weight (FFB) were measured. Each subject also completed a 3.22-km run. The physiological variables resulted in a multiple correlation of $\bar{R} = .91$, thereby accounting for 83% of the variance in run time. Running economy and VO_{2max} were found to be the most potent predictors, each accounting for 21.8% of the variance in the run time. In conclusion, the authors stated that oxidative factors (VO_{2max} , RE, and VT) and FFB contributed significantly to middle-distance running performance while AC, LS, and FW did not account for additional variance.

Triathletes

Albrecht et al. (1986) used a laboratory simulated triathlon to determine VT and lactate threshold (LT) to use for intensity determination in nine experienced triathletes. Subjects performed graded exercise tests on the bicycle ergometer (BE), treadmill (TM), and the swim bench (SB) to measure VO_{2max} , maximal lactate concentration (HLA_{max}), and ratings of perceived exertion (RPE). The results showed VO_{2max} (ml/kg/min) values on the three tests of: 30.43 ml/kg/min for SB, 56.26 ml/kg/min for BE, and 57.59 ml/kg/min for TM. Mean values for LT and VT were

not significantly different between the three testing modes. The authors concluded that the use of laboratory predicted thresholds may actually under-predict race pace.

Mayers et al. (1986) studied 18 triathletes during maximal treadmill running to determine the effects of prior cycling on running performance. Maximal oxygen uptake, AT, and treadmill running time were the variables measured. All subjects completed an initial maximal treadmill test (MTM1), a maximal bicycle ergometer test (MBE), and a second maximal treadmill test (MTM2) separated by a minimum of 72 hours. Experimental subjects ($\underline{n} = 9$) rode the bicycle ergometer for 45 minutes just prior to the MTM2 test at individually determined AT. No significant difference was found for the control subjects ($\underline{n} = 9$) on all measured variables. The experimental subjects showed no significant differences on VO_{2max} or AT, but a significant drop in treadmill running time was found between MTM1 and MTM2 (15.22 min vs. 14.08 min). These results illustrated that triathlete maximal running time on a treadmill after a prolonged intense ride on a bicycle ergometer is impaired even though VO_{2max} is unaffected.

Dengel et al. (1986) used eleven male triathletes to determine relationships between oxygen consumption and heart rate during submaximal and maximal freestyle swimming

(FS), bicycle ergometry (BE), and treadmill running (TR) and each performance segment of a triathlon. Correlations found between swimming, cycling, and running economy ($\text{VO}_{2\text{max}}$) and performance in the corresponding segments of the race were .91, .78, and .86, respectively. Maximal oxygen uptake values (FS = 4.17 l/min, BE = 4.68 l/min, TR = 4.81 l/min) were less related to performance times with r values of -.49, -.32, and -.55 for swimming, cycling, and running, respectively. Running and cycling times from the triathlon were significantly related to the overall triathlon times, $r = .97$ and $.81$, respectively, but swimming was not as highly related ($r = .30$). It was concluded that economy of effort is of a greater importance than $\text{VO}_{2\text{max}}$ to a triathlete's performance.

Kohrt et al. (1986) tested eight male triathletes four times (March, May, July, & September) to assess longitudinal responses to multiple training modes. All subjects were training for the same half-triathlon (1.2-mi swim, 56-mi bike, 13.1-mi run) but training methods and volume were left up to each subject. Training volume was recorded weekly. Maximal oxygen uptake was measured by open circuit spirometry during TR, BE, and tethered swimming (TS). Lactate threshold (VO_2 at blood lactate concentration of 4 mM) was measured from fingertip blood

samples. Mean VO_2max values from the first test date for the TR, BE, and TS tests were 57.4, 53.4, and 48.3 ml/kg/min, respectively, and 58.4, 56.0, and 47.8 ml/kg/min for the fourth test date. The only significant increase in VO_2max was for the BE (4.9%). An increase in VO_2 at lactate threshold was found for both treadmill (80.55 to 84.6%) and bicycle (72.3 to 75.8%) tests from the first to the fourth test periods, although it was not stated if it was a significant increase. Authors concluded that magnitude of improvement depended mainly on training volume for each event; and since equal improvement was not seen in all areas, the data supports the theory of training specificity.

Skinner et al. (1986) tested eight male triathletes on the Wingate Anaerobic Test. Resistance was set at 50 and 75 gm/kg body weight for arm and leg testing, respectively. Anaerobic power, AC, and FI were measured in March, May, July, and September. Significant increases in arm and arm/leg AP and AC were found from the March to September test dates, with no significant increase for leg AP and a significant decrease in mean leg AC (8.4 to 8.2 W/kg). The drop in leg AC was paralleled by an increase in mean VO_2max (53 to 56 ml/kg/min). Fatigue indices were all below 50%, which the authors stated was due to a low percentage of

fast-twitch fibers in these endurance athletes. In conclusion, triathlon training was found to have little effect on anaerobic performance, except for in the arms, possibly due to lack of training in the athletes studied.

Six male triathletes were tested to assess their response to prolonged strenuous competition by Holly et al. (1986). A three day diet analysis, resting 12-lead EKG, blood sample, graded treadmill test, and hydrostatic weighing were measured on the triathletes. All subjects competed in the 1984 Ironman triathlon. Average daily training for the four top male competitors was 2720 m swimming, 13.6 km running, and 84.0 km bicycling. Mean VO_2max and percent body fat were 72.0 ml/kg/min and 7.1%, respectively. Performance times in the race were 9.68 hr for the top four males and 11.87 hr for the other two males.

Rogers et al. (1986) tested the response of runners to a triathlon competition with canoeing in place of the swimming leg. Twenty-one male athletes ($\bar{M}$ age = 29.1 yr and $\bar{M}$ weight = 77.2 kg) who were primarily runners, trained for four months prior to competing in an "Ironman" triathlon (20-km canoe, 90-km cycle, and 42-km run). Maximal oxygen uptake, basal and post-race blood samples, and performance time were all obtained. Mean VO_2max was

4.26 l/min or 55.0 ml/kg/min. Mean performance times were 2.54 hr for canoeing, 3.83 hr for cycling, and 4.61 hr for running. Total performance time was not related to absolute $\dot{V}O_{2\max}$ ($r = -.15$), but was well correlated with relative $\dot{V}O_{2\max}$ ($r = -.60$). Running performance was related to $\dot{V}O_{2\max}$ (ml/kg/min) only slightly ($r = -.43$), indicating that the cumulative effects of canoeing and cycling may have adversely affected running performance.

Kohrt et al. (1987) sought to develop a physiological profile for a group of trained triathletes and to determine whether general or specific adaptations resulted from multiple modes of training. Thirteen triathletes ($\bar{M}$ age = 29.5 yr & $\bar{M}$ body weight = 69.8 kg) with an average of two years triathlon experience were tested over a six-week period during which they participated in a half-triathlon (1.2-mi swim, 56-mi bike, and 13.1-mi run). Maximal oxygen uptake was measured during the test period on a TM, BE, and with TS. Average $\dot{V}O_{2\max}$ values for each test were: 60.5 ml/kg/min for TM, 57.9 ml/kg/min for BE, and 52.5 ml/kg/min for TS. Running and cycling times for the triathlon were significantly ($p < 0.01$) related to corresponding $\dot{V}O_{2\max}$ values ($r = -.68$ and $-.78$, respectively), but the swimming times were not ($r = -.50$). The authors concluded that triathletes experience specific training

responses as do single-sport athletes, because they reduce the differences normally seen in VO_2max values in untrained subjects between running and cycling and running and swimming.

O'Toole et al. (1987) developed a physical and physiological profile on eight male triathletes in training for the Hawaii Ironman triathlon. Anthropometric measurements and oxygen uptake during maximal exercise on a treadmill, cycle ergometer, and arm ergometer were obtained. All subjects had been competing for at least three years, and were in training for two months prior to the race. Average weekly training distances were 10.5-km swimming, 304.3-km cycling, and 71.9-km running. Seven of the eight subjects finished the race, with a mean finish time of 11.85 hr. Anthropometric data revealed the triathletes to be most similar in physique to elite cyclists. Oxygen uptake values ranged from 32.6 to 84.5 ml/kg/min for the subjects on all three tests. The triathletes had VO_2max values similar to elite swimmers, but slightly below that of elite runners and cyclists.

Aerobic Work Capacity Tests

Comparisons are often made between two different sports by measuring VO_2max with various techniques. The

most common comparison is between running and cycling. Saltin and Astrand (1967) measured $\dot{V}O_{2\max}$ on 133 athletes from Swedish National Teams, and found that an 8% higher oxygen uptake was elicited for 24 of the subjects on the treadmill than on the bicycle ergometer. This difference has been attributed to a smaller cardiac output (due to a smaller stroke volume) when testing on a bicycle ergometer. The decrease in blood flow out of the heart is said to come from a greater impairment of skeletal muscle blood flow from cycling than running (Faulkner, Roberts, Elk, & Conway, 1971). More recent studies attribute this difference to the specificity of the tests administered. Stromme, Ingjer, and Meen (1977) stated that it is important to select a test situation that allows the optimal use of the specifically trained muscle fibers of the athlete. The test should be as identical as possible to the actual sport activity in question. Hagberg, Giese, and Schneider (1978) tested competitive cyclists in three situations: on a treadmill, on a bicycle ergometer, and on a regular bicycle placed on a treadmill. The bicycle on the treadmill was found to be the best test to simulate actual competition, but the safety factor made it less desirable for mass testing.

As early as 1967 comparisons were made between

running, cycling, and swimming VO₂max tests (Magel & Faulkner, 1967). Holmer (1972) measured these three parameters on swimmers and found a much lower VO₂max value from the swimming test as compared to the other two. Also in 1972, Holmer and Astrand used all three methods of aerobic capacity measurement on a set of twins. They found significantly higher (49%) swim VO₂max values for the twin who was a trained swimmer. Other research on the specificity of VO₂max tests (Secher & Oddershede, 1974; Magel et al., 1975; McArdle, Magel, Delio, Toner, & Chase, 1978) has come to the general conclusion that the best test of VO₂max is one that most closely duplicates the athlete's individual activity.

Many researchers over the past twenty years have investigated the benefits and/or limitations of administering combined arm-leg ergometry VO₂max tests as opposed to leg ergometry or treadmill tests. In 1961 Astrand and Saltin compared VO₂max and heart rate in seven different types of muscular activity: bicycle ergometry (both seated and supine), combined arm-leg ergometry, running on a treadmill, skiing, swimming, and arm cranking. They found almost identical mean VO₂max values for combined arm-leg work as for the leg work alone in a sitting position (4.24 l/min and 4.23 l/min. respectively). They

concluded that the limitation for $\dot{V}O_{2\max}$ was independent of the mass of muscle used as soon as it exceeded a certain mass.

Gleser, Horstman, and Mello (1974) pointed out that Saltin and Astrand reduced the leg load when adding arm work, thereby causing the leg work to be submaximal and eliciting a lower or equal $\dot{V}O_{2\max}$ when combining the arm and leg work. Gleser et al. (1974) attempted to clear up this controversy by comparing leg work with combined arm-leg work. A 10% mean increase in $\dot{V}O_{2\max}$ was obtained when subjects added arm work to the leg work (3.09 l/min for legs only, and 3.39 L/min for arm-leg work). Maximum heart rate and $\dot{V}O_2$ did not differ significantly between the two types of work. The authors concluded that the additional muscle mass of adding the arms allowed the subjects to attain a higher $\dot{V}O_{2\max}$.

Reybrouck, Heigenhauser, and Faulkner (1975) sought to identify the variables that might be limiting the $\dot{V}O_{2\max}$ of subjects with widely different aerobic capacities during exercise of varying muscle masses. They tested only three subjects, but each subject performed an average of eleven maximal tests as arm cranking, leg ergometry, or combined arm-leg ergometry. They found that the arm $\dot{V}O_{2\max}$ was 68% of the leg $\dot{V}O_{2\max}$, but only 60% of the combined task. One

subject who had a high aerobic capacity at the start (64 ml/kg/min) elicited a 5.42 l/min $\dot{V}O_{2\max}$ for the legs alone and a 5.25 l/min for the combined task. The two other subjects obtained only 82% and 84% of the combined task's $\dot{V}O_{2\max}$ value on the leg work test. The authors concluded that a critical factor in obtaining a higher $\dot{V}O_{2\max}$ with combined arm-leg ergometry, as opposed to leg ergometry, appears to be the degree to which the subject is conditioned for leg ergometry.

Bergh, Kanstrup, and Ekblom (1976) examined the relative contribution of arm work to the total work performed, and also the comparison of combined arm-leg work to leg work and uphill treadmill running. They took ten well-trained ($\dot{M} \dot{V}O_{2\max} = 60.7$ ml/kg/min) subjects and had them perform arm-leg ergometry with the arm intensity at 10%, 20%, 30%, and 40% of the total intensity. They also performed a maximal bicycle and treadmill test. Mean $\dot{V}O_{2\max}$ values for the different tests were: running 4.44 l/min, bicycling 4.12 l/min, arm cranking 3.01 l/min, and combined arm-leg 4.32, 4.34, 4.27, and 4.01 l/min for the various intensities. Authors concluded that for use of combined arm-leg $\dot{V}O_{2\max}$ tests, 20% of the total load should be performed by the arms. This type of test appears to be

Seals and Mullin (1982) tested well-trained upper body (WTUB) athletes and untrained subjects on four different types of exercise: arm cranking (AC), leg cycling (LC), graded treadmill running (TR), and combined arm-leg exercise (A+L). The subjects were 12 rowers, 10 gymnasts, 11 swimmers, 10 wrestlers, and 12 non-WTUB individuals. The authors' purpose was to see what differences exist in VO₂max attained in different types of exercise across groups of non-WTUB subjects and WTUB athletes from various sports. Combined arm-leg VO₂max values were 115%-132% of the LC VO₂max values, which was significant across all five groups of subjects. Differences between VO₂max values for the TR and A+L tests were not significant for the crew, gymnastics, or swimming groups. However, the A+L values for the wrestlers and non-WTUB groups were significantly lower than their TR values. The authors thus concluded that WTUB athletes appear to attain a higher VO₂max than non-WTUB individuals whenever the mode of exercise involves substantial use of

capacity among the variously trained WTUB groups were more apparent under the acute stress of A+L exercise than in AC alone.

Discriminant Analysis Studies

Discriminant analysis is a statistical technique that allows for the differentiation between groups or categories on the basis of relationships with many discriminating variables (Williams, 1986). It can be used to describe the difference between groups, and as a basis to classify new cases into appropriate groups.

Pollock, Jackson, and Pate (1980) took 20 elite distance runners (eight marathon and 12 middle-long distance runners) and eight good runners to try to evaluate and quantify physiological differences among the groups. The variables used were: fat weight, lean weight, $VO_{2\text{submax}}$, blood lactate concentration after submaximal work, and $VO_{2\text{max}}$. Multivariate analysis of variance (MANOVA) was used to determine if the groups were different, and discriminant analysis was used to find the nature of these differences. The MANOVA was significant at the $p < 0.01$ level, showing that the three groups were different. Discriminant analysis showed that both discriminant functions were significant. Discriminant

function 1 (DF1) was a general physiological capacity dimension and separated the good runners from the elite runners. Discriminant function 2 (DF2) separated the elite marathon and middle-long distance runners. Discriminant function 1 accounted for 80.5% of the variability among groups and DF2 the remaining 19.5%. Seventy-eight percent of all the runners were correctly classified into their respective groups. The authors concluded that, in general, discriminant analysis can be used to identify

combination and relative importance of variables essential for high level athletic performance.

Housh, Thorland, Johnson, et al. (1984) sought to assess the degree to which body composition variables discriminate between successful participants of different sports. Whether these variables could differentiate between sprint and distance athletes was also examined. The subjects were 110 elite adolescent athletes ($\bar{M}$ age = 16.08 yr). Sixty-four of the subjects were swimmers and 46 were track and field athletes. All subjects were classified as either sprint or distance performers. Body weight, lean body weight, fat weight, and relative fat were assessed. Multiple discriminant analysis (DA) was used to see if body composition variables alone were sensitive enough to differentiate between groups and also to

correctly classify the individuals. The discriminant analysis correctly classified 87.3% of the subjects as either swimmers or runners ($p < 0.05$). Validation of the discriminant function indicated an overall 80.6% correct classification ($p < 0.05$). No significance was found when separate multiple DA were used to determine if the body composition variables could be used to discriminate between distance and sprint athletes. The researchers concluded that body composition information should be used for competitive standards guidelines and fitness analysis.

Housh, Thorland, Tharp, and Cisar (1984) determined the extent to which anthropometric and body build variables discriminated between elite adolescent male athletes from different track and field events. The subjects were 106 national-level Junior Olympic male athletes, of which 26 were middle distance runners, 24 sprinters/hurdlers, 39 jumpers, and 17 throwers. Fat-free body weight/height (FFB/Ht), the sum of six skinfolds (SUM-SF), the sum of 12 diameters (SUM-D), the sum of 11 circumferences (SUM-C), biacromial diameter/bi-iliac diameter (BA/BI), and the bi-dimensional somatotype ratings were all measured.

Multiple discriminant analysis found that

DF1 which represented anthropometric and body build differences between middle distance runners and throwers. It was concluded that anthropometric and body build variables are moderately sensitive in discriminating between elite male track athletes, but body composition and metabolic factors should also be assessed to further define successful performers.

Cisar et al. (1987) used the technique of multiple discriminant analysis to see if preseason body composition, build, and strength could predict wrestling success in the upcoming season. Fifty-five male high school wrestlers ($\bar{M}$ age = 16.2) were subjects for the study. The wrestlers were divided into highly-skilled ($\bar{n}$ = 14), average ($\bar{n}$ = 13), and novice ($\bar{n}$ = 28) groups based on their win-loss records. Variables included body weight, relative fat, fat weight, lean body weight, sum of four skinfolds, height, diameters, and circumferences. Leg and arm strength (flexion and extension) were assessed on the Cybex isokinetic dynamometer. The discriminant analysis revealed two functions (DF1 & DF2) each accounting for 50% of the variance in wrestling performance. Discriminant function 1 was characterized by the strength relative to body weight variables, whereas DF2 consisted of mostly the body composition and body build variables. Sixty-four

percent of the highly-skilled and 75% of the novice wrestlers were correctly classified. However, only 8% of the average wrestlers were correctly classified. The authors concluded that the variables measured were fairly sensitive in predicting success for the highly-skilled and novice wrestlers, but not for average wrestlers.

Summary

Many physiological factors have been reported as determinants of performance for runners, cyclists, swimmers, and triathletes in this review of literature. The factors assessed include variables of cardiorespiratory endurance, muscular strength and endurance, and body composition and build characteristics. Specific measurements of these factors are: VO_{2max} , running economy, ventilatory threshold, height, weight, relative fat, lean body weight, fat weight, leg and arm strength, anaerobic power and capacity, fatigue index, and body somatotypes. Most of the previous research has investigated some of these variables on athletes from one of the component sports of the triathlon. None of the previous studies have examined all of these variables simultaneously on triathletes.

Therefore, in order to assess the physiological

determinants of triathlete performance, this investigation attempted to differentiate between the HiS, AvS, and LeS triathlete with the use of discriminant analysis for the benefit of current and future triathletes.

CHAPTER III

METHODS

Introduction

In this chapter information on the subjects, the measurements and methods, and the experimental design, and the scoring of data are presented.

Subjects

The subjects in this study were forty-three healthy male volunteers between the ages of eighteen and forty-five, with varying levels of triathlon experience. After being screened for age and personal health history (Appendix B), the first forty-three subjects to respond to flyers were accepted into the study. All subjects were entrants in the Bud Light USTS 1987 Triathlon held in San Jose, California on Sunday August 30, 1987. Subjects were divided into the HiS ($n = 15$), AvS ($n = 14$), and LeS ($n = 14$) performance levels based on their net triathlon times. Current training mileage and years of triathlon experience were also obtained from each applicant (Appendix B). All procedures were fully explained to the subjects and an informed consent (Appendix A) approved by the Human Subjects Institutional Review Board of SJSU was

obtained from each subject prior to any data collection.

Measurements and Methods

The subjects reported to the lab on the day of data collection having been previously told not to exercise for at least 12 hours prior and not to eat, drink, or smoke for three to four hours prior to test time.

The laboratory tests were executed in the following order: leg, shoulder, and arm strength; anthropometric measurements; anaerobic work responses; body composition; and maximal aerobic responses. The performance variable was a middle distance triathlon (1.5-km swim, 45-km bike, 11-km run) performed within one month of laboratory tests.

Aerobic Work Indices

Aerobic capacity was tested using combined arm and leg ergometry on a Monark 650 bicycle ergometer and a Monark 881 arm ergometer. Subjects were fitted with headgear to support a Hans-Rudolph respiratory valve and mouthpiece. Inhaled air passed through a Parkinson-Cowan CD-4 dry test meter and into the respiratory valve. A potentiometer connected to a Gilson recorder, model 5/6H, was used to record the volume of inspired air. Expired air passed out of the Rudolph valve into a mixing chamber

from which samples of air were analyzed.

A Wilmore-Costill Spinner Valve (WCSV) system was used to analyze the oxygen (FeO_2) and carbon dioxide (FeCO_2) concentrations of the expired air. The expired gases passed over a dessicated column to remove water vapor then passed through the mixing chamber into the WCSV system and into the analyzers. A Beckman LB-2 Medical Gas Analyzer and an Applied Electrochemistry S-3A analyzer determined the respective CO_2 and O_2 concentrations. The analyzers were calibrated before and periodically during each test with a standard gas sample. Data for inspired air and gas concentrations of the expired air were collected every minute of the test

was lined up with the subject's glenohumeral joint and adjusted to allow for near full extension of the arm (Reybrouck et al., 1975; Seals & Mullin, 1982). A ten second resting (pre-exercise) EKG strip was obtained prior to the start of the test. The test procedures were then reviewed, and any questions answered.

For warm-up purposes a period of approximately one minute at zero kg was used. The test consisted of three minute stages at an initial combined workload of 1.0 kg (0.25 kg arms and 0.75 kg legs) with a pedal cadence of 60 rpm until voluntary exhaustion (Bergh et al., 1976; Seals & Mullin, 1982). Every three minutes the resistance was increased by 1.0 kg (0.25 arms and 0.75 legs). A GraLab clock and a metronome were used to maintain time intervals and pedalling cadence. Exhaustion was defined as a failure to maintain the required 60 rpms (Seals & Mullin, 1982). Failure to maintain 60 rpms was determined by a comparison of the rate of the metronome (set at 120), the rpm monitor on the arm ergometer, and the subject's leg crank rate. The test was terminated if any of following conditions occurred: (a) a signal by the subject that he did not want to continue, (b) a failure of heart rate to increase with increasing workloads, (c) pain or fatigue as

indicated by lessened coordination or pallor, (d) any abnormalities in the EKG, (e) failure of the EKG equipment or (f) a failure to maintain 60 rpm (+ 5 bpm). Subjects were instructed to stay seated throughout the test.

To prevent venous pooling of blood in the arms and legs, a three to five minute cool-down period followed the maximal test. When the subject's heart rate was below 120 bpm, a post exercise EKG strip was obtained and the subject was allowed off the arm/leg ergometer.

Expired ventilation (VE) was calculated from inspired ventilation (VI). Oxygen uptake (VO₂) and carbon dioxide production (VCO₂) rates were calculated from VI, VE, FeO₂, and FeCO₂ values. Environmental data (barometric pressure, relative humidity, and room temperature) was collected for each subject's test period, and used to correct ventilation and gas values to STPD.

Anaerobic Work Indices

Anaerobic power, anaerobic capacity, and fatigue index were measured using the Wingate test on a Monark bicycle ergometer and a Monark arm ergometer. Prior to the start of the test, the seat of the ergometer was adjusted so that the subject's legs were near full extension when pedalling and the axis of the crank arm of the arm ergometer was

slow pedalling against zero resistance interspersed with one sprint of four to five seconds (Bar-Or, 1978; Inbar & Bar-Or, 1975). After the warm-up the subject rested for about two minutes during which time the procedures for the 30-second test were reviewed. At the command "GO", the subject began pedaling as fast as possible while the investigator increased the resistance to 0.050 and 0.060 X body weight (kg) for the arms and legs (Skinner, Kohrt, & O'Connor, 1986), respectively, within the first two to three seconds (Bar-Or, 1978; Tharp et al., 1984; Tharp et al., 1985). As soon as the workload was set, the thirty second test began, during which time the subject was encouraged to give a maximal effort. The workload and elapsed time was monitored closely throughout. A two to four minute cool-down followed the test to prevent muscle soreness and dizziness (Thorland, Johnson, Cisar, Housh, & Tharp, 1987). Anaerobic power was calculated as the highest kgm/5-sec work interval and anaerobic capacity as total kgm/30-sec work interval (Bar-Or, 1978; Tharp et al., 1984; Tharp et al., 1985). Fatigue index was calculated as the highest 5-sec peak power minus the lowest 5-sec

peak power, divided by the highest 5-sec peak power, multiplied by 100 (Bar-Or, 1978).

Leg, Shoulder, and Arm Strength

Leg Strength

Leg strength was measured on a Cybex II+ isokinetic dynamometer. Subjects were seated on an adjustable chair with the thigh, hips, and chest stabilized by velcro straps. The axis of rotation of the dynamometer was aligned with the subject's anatomical axis of rotation at the knee joint and the distal end of the lever arm was strapped to the leg just proximal to the malleoli of the ankle (Isolated-Joint Testing & Exercise: A handbook for using the Cybex II+ and the U.B.X.T., 1983). Leg strength was obtained from the subject's dominant leg (determined by kicking preference) extension through a 90 degree range of motion that ended at full extension. Three to four submaximal trials preceded the actual test, for warm-up purposes. The subject then executed three maximal extensions at 30, 180, and 300 degrees/sec. The highest peak torque extension value at 180 degrees/sec was used (Clarkson et al., 1982; Gilliam et al., 1979; Housh, Thorland, Tharp & Cisar, 1984; Haymes & Dickinson, 1980).

Arm and Shoulder Strength

Arm and shoulder strength were also measured on the Cybex II+ isokinetic dynamometer utilizing the Upper Body Exercise Table (U.B.X.T.) attachments. Subjects were in a reclined position on the U.B.X.T. bench, with their upper body stabilized by velcro straps. The axis of rotation of the dynamometer was aligned with the subject's anatomical axis of rotation at the elbow and shoulder

(Isolated-Joint Testing & Exercise: A handbook for using the Cybex II+ and the U.B.X.T., 1983).

Arm and shoulder strength were obtained from the subject's dominant arm (determined by throwing preference) extension through a 180 degree range of motion. Three to four submaximal trials preceded the actual test, for warm-up purposes. The subject then executed three maximal extensions at 30, 180, and 300 degrees/sec. The highest peak torque extension value at 180 degrees/sec was used (Clarkson et al., 1982; Gilliam et al., 1979; Housh, Thorland, Tharp & Cisar, 1984; Haymes & Dickinson, 1980).

Body Composition

An estimation of body composition was obtained from underwater weighing, with corrections made for residual

lung volume by the helium dilution method (Systems Manual for Collins Residual Volume, Pulmonary Function Testing System, 1983). Body weight in kg was measured for all subjects. Residual lung volume was measured with a Collins RS Unit as the average of two to three trials. Underwater weighing was assessed in a metal tank in which a webbed sling was suspended from a Chatillon scale. Subjects performed six to ten trials by exhaling as much air as possible while submerged under the water. The highest three scores (within 0.15 kg) were averaged to obtain the underwater weight (Thorland, Johnson, Fagot, Tharp, & Hammer, 1981). Relative fat (RF) was calculated from the formula of Brozek et al. (1963) and lean body weight and fat weight were calculated from the values for body weight and relative fat.

Anthropometry

Height and anthropometric measurements were obtained for the determination of body build characteristics. Height was measured using a wall scale with a Broca plane to the nearest 0.1 cm. Lange calipers (10 g/mm² constant pressure) were used to measure skinfold thicknesses at the triceps, subscapular, midaxillary, supra-iliac, abdominal, thigh, chest, and calf sites, with the average of at least

two repeated trials within 0.5 mm of each other used as the representative score. Wrist, elbow, bicep, biacromial, chest, bi-iliac, bitrochanteric, knee, and ankle diameters were measured with a broad-blade metal anthropometer to the nearest 0.1 cm. Circumferences were taken at the wrist, forearm, extended arm, flexed arm, shoulders, chest, abdomen I and II, hips, thigh, knee, calf, and ankle with a Lufkin metal tape fitted with a Gullick handle, also to the nearest 0.1 cm. Anthropometric sites used in this study are those described by Behnke and Wilmore (1974). These measurements were then used to mathematically calculate body somatotypes using the anthropometric rating methods as described by Heath and Carter (1967). The three-component body somatotype rating (endomorph, mesomorph, and ectomorph) were converted to the bi-dimensional scores, X and Y, as stated by Ross and Wilson (1973).

Scoring of Data

The values for body weight, STPD, BTPS, as well as $\dot{V}I$, $\dot{V}E_{O_2}$, and $\dot{V}E_{CO_2}$ values obtained from the incremental combined arm/leg aerobic ergometer test for each subject were entered into a microcomputer program for further analysis. The program computed $\dot{V}E$ (l/min, BTPS), $\dot{V}O_2$ (l/min), $\dot{V}CO_2$ (l/min), respiratory exchange ratio

($\text{VC02}/\text{V02}$), and V02 ($\text{ml}/\text{kg}/\text{min}$) values for each minute of the incremental ergometer test. The same microcomputer program also calculated the cumulative and delta standard error of estimate values for the linear correlation between VE (l/min) and V02 (l/min) and graphed a scatter plot for consecutive minutes of VE (l/min) against V02 (l/min). Maximal oxygen uptake and VT were then determined using criteria defined in Chapter I.

Anaerobic work indices and body composition measurements were determined using calculations explained in Chapter I. Triathlon performance times were obtained for each subject from the official Bud Light USTS race results. Total net time was obtained by subtracting the total transition time from the total overall time for each subject. This value was used for statistical analysis because the transitions are not indicative of physiological ability, but more of experience. Total net time was then converted into minutes and expressed to the nearest hundreth for statistical analysis.

Descriptive statistics ($\bar{M} \pm \text{SD}$) were used to describe the group's overall characteristics. The relationships between these descriptive characteristics were explored by the use of Pearson product-moment correlations. One-way analysis of variance and Tukey

post-hoc tests were used to determine the mean differences across skill levels on the descriptive characteristics. A full-model and stepwise multiple regression analysis was used to examine the relationship between the physiological variables and performance time in the triathlon for the overall group of subjects. The SPSSX (SPSSX User's Guide, 1983) computer program was used for statistical analysis of the data.

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

This chapter includes the analysis of results, and the discussion of results.

Analysis of Results

Table 1 shows the descriptive characteristics for the overall group of subjects. The $\bar{M} \pm SD$ age and height of the subjects was 32.20 ± 6.18 yr and 178.37 ± 6.58 cm, respectively. The mean triathlon performance time (total net time) of the subjects was 175.40 ± 24.32 min.

Table 2 summarizes the comparison of descriptive characteristics of the subjects across skill levels, as well as the results of the one-way analysis of variance and Tukey post-hoc tests used to examine the mean differences in the descriptive characteristics of the subjects across skill levels. The HiS group ($n = 15$) had a mean performance time (TNT) of 152.79 min, the AvS group ($n = 14$) had a mean performance time of 170.67 min, and the LeS group ($n = 14$) had a mean performance time of

Table 1

Descriptive characteristics of the subjects ($n = 43$).

Characteristic	<u>M</u> $\pm$ <u>SD</u>	
Age (yr)	32.20 $\pm$	6.18
Height (cm)	178.37 $\pm$	6.58
Body weight (kg)	74.98 $\pm$	7.72
Relative fat (%)	13.67 $\pm$	5.64
Fat weight (kg)	10.40 $\pm$	5.20
Lean body weight (kg)	64.58 $\pm$	6.67
Leg strength (ft-lbs)	101.16 $\pm$	18.05
Shoulder strength (ft-lbs)	55.70 $\pm$	9.29
Arm strength (ft-lbs)	33.54 $\pm$	5.89
Anaerobic power (kgm/5 sec)	453.03 $\pm$	64.60
Anaerobic capacity (kgm/30 sec)	2172.79 $\pm$	336.56
Fatigue index (%)	35.60 $\pm$	7.68
Ventilatory threshold (l/min)	2.68 $\pm$	0.47
Maximal oxygen uptake (l/min)	4.25 $\pm$	0.56
X (linearity-fatness)	-0.95 $\pm$	1.86
Y (muscularity)	2.49 $\pm$	2.69
Total net time (min)	175.40 $\pm$	24.32

Table 2

Comparison of descriptive characteristics of the subjects
across skill levels.

Characteristic	Group I Highly skilled (<u>n</u> = 15)	Group II Average skill (<u>n</u> = 14)	Group III Lesser-skilled (<u>n</u> = 14)
Body Weight(kg)	73.79 $\pm$ 2.30 (56.40-91.60)	74.41 $\pm$ 1.57 (62.40-86.80)	76.83 $\pm$ 2.06 (66.45-92.25)
^a Relative fat (kg)	10.03 $\pm$ 0.51 (5.30-12.60)	13.91 $\pm$ 1.09 (8.20-25.00)	17.31 $\pm$ 1.93 (9.60-38.00)
^a Fat Weight(kg)	7.42 $\pm$ 0.48 (3.99-10.84)	10.40 $\pm$ 0.90 (6.28-19.09)	13.59 $\pm$ 1.91 (8.02-35.08)
Lean Body weight(kg)	66.37 $\pm$ 2.12 (49.66-80.76)	64.01 $\pm$ 1.44 (55.15-72.03)	63.24 $\pm$ 1.60 (56.73-77.39)
Leg strength (kg)	98.07 $\pm$ 5.02 (71.00-140.0)	98.79 $\pm$ 4.40 (81.00-129.0)	106.86 $\pm$ 4.80 (82.00-144.0)
Shoulder strength (ft-lbs)	56.27 $\pm$ 2.74 (44.00-83.00)	55.93 $\pm$ 2.27 (42.00-68.00)	54.86 $\pm$ 2.46 (44.00-72.00)
Arm strength (ft-lbs)	32.93 $\pm$ 2.17 (22.00-47.00)	32.57 $\pm$ 1.00 (25.00-37.00)	35.14 $\pm$ 1.13 (26.00-42.00)
Anaerobic power (kgm/5 sec)	449.81 $\pm$ 20.76 (264.00-587.30)	439.89 $\pm$ 14.10 (330.00-504.00)	469.61 $\pm$ 15.22 (405.00-567.00)

Values are M $\pm$ SEM (range).

^a

One-way ANOVA significant at $p < 0.05$ and Tukey post-hoc difference between groups I & III.

^b

One-way ANOVA significant at $p < 0.05$ and Tukey post-hoc difference between groups I & II and I & III.

^c

One-way ANOVA significant at $p < 0.05$ and Tukey post-hoc difference between groups I & II, I & III, and II & III.

Table 2

Comparison of descriptive characteristics of the subjects
across skill levels (continued).

Characteristic	Group I Highly skilled (<u>n</u> = 15)	Group II Average skill (<u>n</u> = 14)	Group III Lesser-skilled (<u>n</u> = 14)
Anaerobic capacity (kgm/30 sec)	2198.71 $\pm$ 102.29 (1248.0-2856.0)	2138.14 $\pm$ 62.74 (1660.5-2367.0)	2179.65 $\pm$ 99.90 (1413.0-2989.0)
Fatigue index(%)	32.84 $\pm$ 1.48 (16.49-39.54)	35.41 $\pm$ 1.87 (20.10-44.18)	38.74 $\pm$ 2.49 (19.51-55.04)
Ventilatory threshold(l/min)	^b 2.95 $\pm$ 0.16 (2.00-4.27)	2.52 $\pm$ 0.08 (1.91-2.98)	2.54 $\pm$ 0.08 (2.04-3.26)
Maximal oxygen uptake(l/min)	^b 4.66 $\pm$ 0.13 (3.98-5.75)	4.10 $\pm$ 0.14 (3.00-5.10)	3.97 $\pm$ 0.10 (3.41-4.65)
X (linearity - fatness)	^a 0.13 $\pm$ 0.34 (-2.26-1.86)	-1.20 $\pm$ 0.43 (-4.84-0.97)	-1.85 $\pm$ 0.57 (-3.59-5.79)
Y (muscularity)	2.44 $\pm$ 0.82 (-4.24-7.95)	2.89 $\pm$ 0.60 (-1.94-6.24)	2.14 $\pm$ 0.71 (-3.59-5.79)
Total net time(min)	^c 152.79 $\pm$ 2.04 (132.22-159.82)	170.67 $\pm$ 1.99 (160.21-183.39)	204.37 $\pm$ 4.39 (186.83-243.28)

Values are M $\pm$ SEM (range).

^a

One-way ANOVA significant at $p < 0.05$ and Tukey post-hoc difference between groups I & III.

^b

One-way ANOVA significant at $p < 0.05$ and Tukey post-hoc difference between groups I & II and I & III.

^c

One-way ANOVA significant at $p < 0.05$ and Tukey post-hoc difference between groups I & II, I & III, and II & III.

204.37 min. Relative fat, fat weight, and X differed significantly between the HiS and LeS triathletes. Ventilatory threshold and maximal oxygen uptake differed significantly between the HiS and both the AvS and LeS groups. Total net time increased significantly from the HiS to the AvS to the LeS athletes. No differences were observed between skill levels for body weight, lean body weight, leg strength, shoulder strength, arm strength, anaerobic power and capacity, fatigue index, and Y at the $p < .05$ level of significance.

Table 3 represents the zero-order correlation matrix between the descriptive characteristics for all 43 subjects. Significant intercorrelations ($p < .05$) were found between many of the physiological variables with high intercorrelations identified between relative fat and fat weight ($r = .98$), leg strength and anaerobic power ($r = .82$), and anaerobic power and anaerobic capacity ($r = .82$). The significant intercorrelations between many of these variables suggests that there may be groups of these variables that are represented by underlying common functions.

Table 4 summarizes the rotated standardized discriminant function coefficients of the physiological variables for the entire group of subjects. The absolute

Table 3

Zero-order correlation matrix for the descriptive characteristics of the subjects ($n = 43$).

	BW	RF	FW	LBW	LS	SS	AS	AP	AC	FI	VT	VO2MX	X	Y	TNT
Body Weight	1.00														
Relative Fat	.36	1.00													
Fat Weight	.53	.98	1.00												
Lean Body Weight	.75	-.35	-.17	1.00											
Leg Strength	.72	.13	.26	.64	1.00										
Shoulder Strength	.58	-.16	-.03	.69	.54	1.00									
Arm Strength	.63	.03	.14	.62	.59	.60	1.00								
Anaerobic Power	.78	.07	.22	.73	.82	.68	.66	1.00							
Anaerobic Capacity	.68	-.03	.10	.71	.79	.52	.52	.82	1.00						
Fatigue Index	.01	-.11	.13	-.09	.10	.12	.07	.20	-.20	1.00					
Ventilatory Threshold	.31	-.17	-.09	.43	.20	.13	.19	.30	.39	-.27	1.00				
Maximal Oxygen Uptake	.44	-.22	-.10	.59	.26	.38	.36	.49	.47	-.12	.52	1.00			
X Rating	-.50	-.72	-.73	-.00	-.31	-.08	-.24	-.25	-.15	-.16	.06	.04	1.00		
Y Rating	.16	-.05	-.02	.20	.08	.25	.32	.26	.09	.33	-.02	.21	-.39	1.00	
Total Net Time	.35	.53	.53	-.11	.44	.08	.25	.28	.21	.23	-.23	-.42	-.49	-.08	1.00

Note $r > \pm .30$ required for significance at $p < .05$.

Table 4

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Rotated standardized discriminant function coefficients
for each discriminant function.

<u>Variable</u>	<u>Standardized Coefficients</u>	
	<u>DF 1</u>	<u>DF 2</u>
Fat weight (kg)	-6.894 ^a	-0.113
Relative fat (%)	6.324 ^a	-0.150
Body weight (kg)	2.249 ^a	0.654
Maximum oxygen uptake (l/min)	-0.898 ^a	0.278
Fatigue index (%)	0.704 ^a	-0.184
Leg strength (ft-lbs)	-0.640 ^a	0.046
Ventilatory threshold (l/min)	-0.458 ^a	-0.235
Anaerobic power (kgm/5 sec)	-0.002	-1.709 ^a
Arm strength (ft-lbs)	0.173	-0.749 ^a
Shoulder strength (ft-lbs)	-0.123	0.722 ^a
Y (muscularity)	-0.223	0.710 ^a
Anaerobic capacity (kgm/30 sec)	0.662	0.709 ^a
X (linearity - fatness)	-0.159	0.236 ^a

a

Denotes discriminant function with which the predictor variable is most highly related.

Note: The within group variance for Lean body weight did not meet the tolerance default level of 0.001, and hence was not included in the statistical analysis.

standardized discriminant function coefficients represent the relative importance of each predictor variable to the discriminant functions. Two discriminant functions (DF1 and DF2), each representing separate groupings of variables were identified by the analysis. Discriminant function 1 and DF2 accounted for 78.0 and 22.0% of the variance between the skill levels of triathletes, respectively. Body composition/size and aerobic work indices tended to be most highly related to DF1. Anaerobic work indices and strength/muscularity measurements were most highly related to DF2.

Comparison of the group means (centroids) for each discriminant function in Table 5 indicated that DF1 tended to discriminate primarily between the HiS and AvS triathletes (-1.2848 vs. 0.4103), whereas DF2 tended to discriminate primarily between the LeS and both the AvS and HiS triathletes (-0.7544 vs. 0.3464 and 0.3808).

Table 6 shows that the discriminant functions correctly classified 65.1% of the subjects into their respective skill levels ($p < .05$). Within skill levels, 73.3% of the HiS triathletes, 64.3% of the AvS triathletes, and 57.1% of the LeS triathletes were correctly classified.

The full-model and stepwise multiple regression

analysis for the predicted skill level

Table 5

Group means (centroids) for each discriminant function.

<u>Group</u>	<u>DF 1</u>	<u>DF 2</u>
Highly-Skilled	-1.285	0.381
Average	0.410	0.346
Lesser-Skilled	0.966	-0.754

Table 6

Classification results for predicted group membership.

Predicted group membership

n (percent of total)

Average	14	1 (7.1)	9 (64.3)	4 (28.6)
Lesser-skilled	14	0 (0.0)	6 (42.9)	8 (57.1)

(TNT) from the physiological variables is presented in Table 7. The full-model multiple regression analysis resulted in a multiple R value of .84 and a SEE of 15.93 min. Stepwise multiple regression analysis identified relative fat, leg strength, and maximal oxygen uptake as the significant variables in the model, accounting for 71.0% of the variance in triathlon performance time. Relative fat accounted for 28% of the variance in triathlon performance time, with leg strength contributing an additional 14%, and a final 20% from maximal oxygen uptake. The addition of anaerobic power, arm strength, Y, X, fatigue index, anaerobic capacity, shoulder strength, ventilatory threshold, lean body weight, and fat weight in stepwise multiple regression analysis accounted for the remaining 8% of the variance in triathlon performance time.

Discussion of Results

The purpose of this investigation was to examine the contribution of selected physiological variables in the determination of triathlon performance. Previous investigators have identified distinct characteristics as discriminators of successful performance in the three component sports of the triathlon: running (Bransford & Howley, 1977; Bulbulian et al., 1986; Hagan et al., 1981;

Table 7

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^a
Full-model and stepwise multiple regression and beta
coefficient analysis for the prediction of triathlon
performance time from the physiological variables ($n =$
43).

Predictor variable	<u>Full-model</u>		<u>Stepwise</u>	
	Regression Coefficient	Beta Coefficient	<u>R</u>	<u>F</u>
1. Relative fat(%)	5.445	1.26	0.53	15.75*
2. Leg strength(ft-lbs)	0.066	0.05	0.65	14.30*
3. Maximal oxygen uptake(l/min)	-23.145	-0.53	0.79	21.13*
4. Anaerobic power (kgm/5 sec)	0.053	0.14	0.80	16.77
5. Arm strength (ft-lbs)	0.789	0.19	0.81	13.64
6. Y (muscularity)	-2.325	-0.26	0.81	11.34
7. X (linearity - fatness)	-2.991	-0.23	0.82	10.29
8. Fatigue index(%)	0.738	0.23	0.82	9.04
9. Anaerobic capacity (kgm/30 sec)	0.016	-0.23	0.83	8.10
10. Shoulder strength (ft-lbs)	-0.286	-0.11	0.83	7.16
11. Ventilatory threshold(l/min)	-2.957	0.06	0.83	6.36
12. Lean body weight (kg)	1.199	-0.33	0.83	5.70
13. Fat weight(kg)	-4.706	-1.01	0.84	5.30
(Constant)	78.196			

^a
 $F = 5.30$, $p < 0.0001$; $R = .84$, $SEE = 15.93$ min.
 * $p < 0.05$.

Housh et al., 1986, 1986; Katch & Henry, 1972; Wells et al., 1981), cycling (Hagberg et al., 1979; Perez, 1979; Vrijens et al., 1982), and swimming (Dwyer, 1983; Grimston & Hay, 1986; Price et al., 1983; Vaccaro et al., 1984). Research on triathletes has also focused on the determination of the physiological criteria necessary for optimal performance (Albrecht et al., 1986; Dengel et al., 1986; Holly et al., 1986; Kohrt et al., 1986; Kohrt et al., 1987; O'Toole et al., 1987; Rogers et al., 1986; Skinner et al., 1986). In the present study the variables measured parallel those reported by many of these investigators, encompassing cardiorespiratory, strength, and body composition/build indices.

The descriptive characteristics of the subjects reflected numerous similarities to the athletes from previously reported studies. The mean age, height, body weight, and relative fat scores were comparable to previous research on elite swimmers (Lamb, 1984; McArdle, Katch, & Katch, 1986), professional cyclists (Hagberg et al., 1979; Perez, 1979; Vrijens et al., 1982), competitive runners (Hagan et al., 1981; Housh et al., 1986, in press; McArdle et al., 1986; Pate et al., 1985; Wells et al., 1981) and triathletes (O'Toole et al., 1987).

The mean relative fat score across skill levels of 13.67% classified the triathletes in the present study in with elite swimmers, but well above the values for elite runners and cyclists. Within skill levels the HiS triathletes (Group I) had a mean score of 10.03% well above the 7.1% body fat level of elite Ironman triathletes (Holly et al., 1986), but closer to that of elite cyclists range of 6-9% (Faria, 1984). The LeS triathletes, who had a significantly higher RF score than the HiS triathletes (17.31 vs. 10.03%), were closer to the range for non-elite swimmers (Dwyer, 1983; Price et al., 1983; Vaccaro et al., 1984) and Olympic cyclists studied by Johnson et al. (1985).

The strength scores, which were not significantly different across skill levels, were difficult to compare as only one of the physiological profiles reviewed used muscular strength as a parameter. Cisar et al. (1987) measured arm and leg strength on high school wrestlers and obtained values of 23.29 ft-lbs and 72.67 ft-lbs for the forearm and leg, respectively. Although these values are lower than the strength scores found in the present study, the variance is probably attributable to the age difference.

Aerobic work indices of maximal oxygen uptake and

ventilatory threshold significantly different between the HiS & AvS triathletes and the HiS & LeS triathletes, showing a clear division between skill levels on these parameters. The VO₂max values were consistent with the values from some of the triathlete literature (Albrecht et al., 1986; Kohrt et al., 1986; Kohrt et al., 1987; O'Toole et al., 1986; Rogers et al., 1986; Skinner et al., 1986), but lower than the reported values for elite triathletes, cyclists, and runners (Holly et al., 1986; Dengel et al., 1986S; Hagan et al., 1981; Ready et al., 1984; Sjodin & Svedenhag, 1985). The subjects from Group I showed higher VO₂max values when compared to some of the elite triathletes (Albrecht et al., 1986; Kohrt et al., 1986; & Rogers et al., 1986; Kohrt et al., 1987) who had VO₂max values ranging from 48.1 ml/kg/min to 60.6 ml/kg/min. When compared to other elite triathletes (O'Toole et al., 1986 & Holly et al., 1986) with a range of 66.7 ml/kg/min to 72.0 ml/kg/min, however, Group I (4.66 l/min or 63.0 ml/kg/min) showed lower values.

The ventilatory threshold scores across all three skill levels averaged 12% below the average reported value in the triathlete studies of 75%. It is not possible to ascertain from the available data whether the subjects in the present study elicited higher VO₂max values from the

combined arm/leg ergometry test than they would have on a treadmill or bicycle ergometer test.

Values for anaerobic power, anaerobic capacity, and fatigue index were difficult to evaluate as only Housh et al. (1988) and Skinner et al. (1986) reported on anaerobic indices. Housh et al. found a mean value for 10

of 1753.1 kgm which is 12% lower than the reported value for this investigation ($\bar{M}$ = 2172.79 kgm). Fatigue index was assessed by Skinner et al. on a group of triathletes and a mean value of 39.06% was obtained. The authors stated that this value indicated a high endurance capacity characterized by a low percentage of fast-twitch fibers. In the present study a mean fatigue index of 35.60% was obtained, indicating as in Skinner et al. that the athletes have a high capability for endurance activities and a tendency towards a high percentage of slow-twitch muscle fibers.

Body build characteristics as assessed by the somatotype ratings of X (linearity - fatness) and Y (muscularity) portrayed the average and lesser-skilled triathletes as having a higher endomorphic (fatness) rating than ectomorphic (linearity) rating due to the negative X values. Although the X values for the AvS and LeS triathletes were not significantly different from each

other, the LeS triathletes showed a significantly lower X value (higher fatness rating) than the HiS triathletes. The negative X values do not indicate that the athletes' body fat level is too high ($\bar{M} = 13.67\%$), but merely that for their height (178.37 cm) the triathletes' relative fat level is comparable to that of swimmers rather than runners or cyclists (O'Toole et al., 1987). Swimmers tend to retain more body fat than runners or cyclists, due to buoyancy and thermoregulation requirements in the water. The HiS triathletes obtained a positive X value indicating a higher ectomorphic component than the lower skill levels due to lower relative fat levels and higher overall training mileage. The Y (muscularity) values did not differ significantly across skill levels, but increased from the LeS to the AvS triathletes and then decreased from the AvS to the HiS triathletes. This non-significant decrease when moving to a higher skill level indicates that other physiological variables are better discriminators between triathlete skill levels. Thorland et al. (1981) reported on middle-distance runners with X & Y values of 2.1 and 1.1, respectively. When compared to wrestlers (Cisar et al., 1987), another group of upper-body-trained athletes, the runners' scores show the highly ectomorphic characteristics of weight-bearing athletes.

Performance time (TNT) was the only variable that showed significant differences across all three skill levels indicating that it was a valid criteria to use for the determination of skill levels.

The intercorrelation coefficients demonstrated a wide range of values between the physiological variables ($r = .00$ to $.98$). Body weight and VO_{2max} ($r = .44$) showed a comparable correlation to a study on 26-yr-old cyclists $r = .343$) by Vrijens et al. (1982). Rogers et al. (1986) found a good relationship between mass corrected VO_{2max} and performance time ($r = -.60$), but not between gross VO_{2max} and performance time ($r = -.15$). In the present study the correlation coefficient for performance time and VO_{2max} (l/min) was significant at $-.042$.

Discriminant analysis revealed two discriminant functions (DF1 & DF2) encompassing the 13 physiological variables. Most of the variance between groups (78.0%) was accounted for by DF1, which represented body composition/size and aerobic work indice differences between the HiS and LeS triathletes. These results indicate that athletes in the LeS performance level need to concentrate on decreasing their relative fat percentage and increasing their maximal oxygen uptake value in order to progress up through the average and into the HiS

performance level. Fatigue index and leg strength are also important discriminators at this level.

Anaerobic work indices and strength/muscularity differences between the LeS and both the AvS and HiS athletes were described by DF2. Anaerobic power was the variable that discriminated most between these groups, however, arm and shoulder strength, Y, anaerobic capacity, and X also contributed significantly to DF2. Anaerobic power (non-oxidative or sprint ability) was greater for Group III than for the other two groups, illustrating again the need for a high oxidative energy level in these endurance athletes.

The predictor variables were fairly sensitive discriminators as 73.3% of the HiS, 64.3% of the AvS, and 57.1% of the LeS triathletes were correctly classified. An overall correct classification level of 65.1% was obtained.

Stepwise multiple regression analysis for the overall group of subjects identified relative fat, leg strength, and VO₂max as the significant variables in the model accounting for 62.0% of the variance in triathlon performance time. The addition of anaerobic power, arm strength, X and Y, fatigue index, anaerobic capacity, shoulder strength, ventilatory threshold, lean body weight,

and fat weight accounted for the remaining 8% of the variance in triathlon performance time. The equation for predicted triathlon performance time (min) was: $173.293 + 1.514 (\text{relative fat}) + 0.701 (\text{leg strength}) - 21.048 (\text{maximal oxygen uptake (l/min)})$. Although none of the triathlete studies reviewed reported calculated regression equations on the triathletes, several of the studies on runners did. Several of the authors reported on regression equation models with VO_2max as one of the significant predictors of performance time (Bulbulian et al., 1986; Hagan et al., 1981; Housh et al., 1988). Housh et al. (1986) developed a model with a multiple R of 0.626 accounting for 40% of the variance in two-mile run times. Relative fat and fat-free body weight divided by height were the most significant predictors in this model, with the inclusion of additional variables showing no significant increase in the R value. The regression model developed on the triathletes in this study shows some similarities to previous research on runners, with the common predictor variables being VO_2max and RF, but there is still a need to develop additional equations specifically for triathletes.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Introduction

This chapter contains information on the purpose of this study, the methodology of the study, the summary of results, conclusions, and recommendations.

Purpose of Study

The purpose of this study was to determine the contribution of selected physiological variables in the discrimination of triathlon performance. Physiological variables were measured and performance time in a triathlon assessed to determine the relative contribution of physiological variables to triathlon performance across skill levels.

Methodology of Study

The subjects for this study were 43 healthy male triathletes aged 18 to 45 years. Based on their performance time in a triathlon (1.5-km swim, 45-km bike,

and 11-km run), the subjects were divided into three skill levels: highly-skilled (top third), average (middle third), and lesser-skilled (bottom third), based on performance time in the triathlon. The three groups consisted of fifteen, fourteen, and fourteen subjects, respectively.

Laboratory measurements included: leg strength, arm strength, shoulder strength, anaerobic work indices, body size and composition, and aerobic work indices. Strength measurements were obtained on an isokinetic Cybex II+ dynamometer. Anaerobic power, capacity, and fatigue index were measured using the Wingate test on Monarch combined arm and leg ergometers. Body size and somatotype measurements made were body weight, height, X (linearity - fatness), and Y (muscularity). Relative fat, fat weight, and lean body weight were determined by underwater weighing corrected for residual lung volume. Ventilatory threshold and maximal oxygen uptake were determined from the analysis of expired gas concentrations and volumes during each minute of an incremental combined arm and leg ergometer test to voluntary exhaustion. Performance time for the triathlon was obtained for each subject from the Bud Light USTS official race results. The laboratory testing and the triathlon competition occurred within one month of each other.

Summary of Results

The descriptive characteristics of the subjects revealed many significant differences across skill levels. Body composition characteristics (fat weight and relative fat) increased significantly from the HiS triathletes ($\bar{M}$ = 7.42 kg and 10.03%) to the LeS triathletes ($\bar{M}$ = 13.59 kg and 17.31%). No significant difference was found, however, between the HiS and AvS or the AvS and LeS triathletes on these characteristics. These increases in adipose tissue were paralleled by significant decreases in ventilatory threshold and maximal oxygen uptake from the HiS to both the AvS and LeS triathletes. The body build characteristic X (linearity - fatness) showed a significant difference between the HiS and LeS (0.13 vs. -1.85), but did not differ significantly between any of the other skill levels. Performance time in the triathlon (total net time) showed a significant increase across all skill levels, ranging from a mean of 152.79 minutes for the HiS triathletes up to a mean of 204.37 minutes for the LeS triathletes.

The multiple discriminant analysis identified two discriminant functions (DF1 and DF2) encompassing the underlying groupings of physiological variables. Discriminant Function I represents body size/composition

and aerobic work indices characterized by fat weight, relative fat, body weight, maximal oxygen uptake, fatigue index, leg strength, and ventilatory threshold.

Discriminant function 2 represents anaerobic work indices and strength/muscularity measurements characterized by anaerobic power, arm strength, shoulder strength, Y, anaerobic capacity, and X. The HiS and LeS triathletes were discriminated between to the greatest degree by DF1, indicating that body composition/size and aerobic work indices are most important in a triathlete's training regimen until he wants to advance into the HiS performance level, then other physiological variables become more important. Discriminant Function 2 discriminated more between the LeS triathletes and both the AvS and HiS groups. This data indicates that the strength/muscularity and anaerobic work responses are important variables to emphasize in training for the LeS triathlete in order to move up to the two higher levels of performance.

Full-model multiple regression analysis for the prediction of triathlon performance time from the selected physiological variables across skill levels resulted in a multiple R of .84 and a SEE of 15.93 minutes.

Relative fat, leg strength, and maximal oxygen uptake were identified as the significant variables in the model,

accounting for 28%, 14%, and 20% of the variance in triathlon performance time, respectively. The addition of the ten remaining variables in the model accounted for the last 8% of the variance in triathlon performance time.

Conclusions

Within the limits of this study, the following conclusions were made.

1. The majority of the physiological variables measured were significantly intercorrelated for the overall group of subjects.
2. Discriminant analysis of the physiological variables for the overall group of subjects identified two discriminant functions underlying the intercorrelated physiological determinants of triathlon performance: (a) body composition/size and aerobic work indices, and (b) strength/muscularity and anaerobic work responses.
3. Discriminant function 1 was characterized by the physiological variables: fat weight, relative fat, body weight, maximum oxygen uptake, fatigue index, leg strength, and ventilatory threshold.

4. Discriminant function 2 was characterized by the physiological variables: anaerobic power, arm strength, shoulder strength, Y, anaerobic capacity, and X.

5. Across skill levels the significant physiological variables related to triathlon performance time were: relative fat, leg strength, and maximal oxygen uptake (l/min).

Recommendations

Because the current research on triathletes is limited, the following recommendations for further study are presented:

1. Studies which assess the physiological variables of female triathletes in relation to performance should be undertaken.

2. Studies which take into account other physiological as well as psychological variables as they relate to both male and female triathletes should be conducted.

3. Longitudinal studies on both male and female triathletes should be undertaken to assess training effects.

4. Studies which cross-validate the prediction equation on other populations should be conducted.

5. Studies which relate physiological variables and performance criteria to age should be undertaken.

6. The relationship of triathletes physiological characteristics to other upper body trained athletes should be determined.

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STUDY TO INVESTIGATE THE CONTRIBUTION OF SELECTED
PHYSIOLOGICAL VARIABLES IN THE DISCRIMINATION OF
TRIATHLON PERFORMANCE

STATEMENT OF INFORMED CONSENT -- FOR MUSCULAR
STRENGTH, ANAEROBIC CAPACITY, BODY COMPOSITION AND SIZE,
AND CARDIORESPIRATORY ENDURANCE.

Invitation to Participate

You are invited to participate in a study

investigating the effects of muscular strength, anaerobic work indices, body composition and size, and cardiorespiratory (heart-lung function) endurance characteristics on triathlon performance. This study will be conducted at the San Jose State University campus.

Basis for Selection

You have been selected as a participant because you are a healthy male aged 18 to 45 years who will be competing in the August 28th, 1988 Bud Light Triathlon to be held in San Jose, California. Should you elect to participate, your response to a health history questionnaire will be reviewed by an exercise physiologist and, if satisfactory, you will be asked to participate in the tests described below.

Purpose of the Study

The purpose of this study is to investigate the contribution of selected physiological variables in the determination of triathlon performance.

Explanation of Procedures

Muscular Strength Tests (approximately 20 minutes required)

This test will involve measuring the maximal strength for extension of your dominant leg at the knee joint and dominant arm at the shoulder joint using a Cybex II+

isokinetic strength machine. The Cybex II+ will not generate any resistance at slower speeds of leg or arm movement. At faster speeds of movement the resistance will match the force you produce. For the leg strength test, you will be in a sitting position on a bench and secured at the thigh with a velcro strap for stabilization.. Your leg will be attached to a lever arm of the machine by a velcro strap at the ankle. For the arm strength test, you will be on your back in a reclining position with your upper body stabilized with velcro straps and your hand around a hand grip. Both leg and arm strength tests will begin with three to four warm-up trials, followed by three consecutive maximal extension trials at a moderate speed of movement for determination of leg and arm strength.

Anaerobic Capacity Test (approximately 10 minutes required)

The anaerobic capacity test will consist of pedaling a stationary bicycle and arm cranking simultaneously against resistance as fast as possible for 30 seconds. The test will be preceded by a warm-up period and followed by a cool-down period. The bicycle is fitted with toe clips to reduce the risk of slipping off the pedal. You will begin pedaling against a very light resistance and on the command "GO" will begin pedaling as fast as possible. The resistance will be increased to the appropriate level (based on your body weight) within the first 2-3 seconds of the test. Verbal encouragement will be given to motivate you to give a maximal effort.

Body Composition and Size Test (approximately 30 minutes required)

This portion will involve two testing techniques: anthropometry and underwater weighing. Anthropometry involves measuring height, circumferences, diameters, and skinfold thicknesses at specific body sites. Underwater weighing involves three measures: body weight, body weight while underwater, and residual lung volume (the amount of air left in your lungs after you have fully exhaled). For this test you will be seated in a chair breathing room air through a mouthpiece. At the end of a normal expiration a valve will be turned so you will breathe a mixture of helium and room air from the spirometer. Oxygen will be added to the spirometer as needed. After breathing this

mixture for several minutes you will be asked to inhale fully and then exhale fully. The whole procedure will be repeated as necessary. To obtain body weight while underwater, you will be sitting in a 4 inch wide canvas sling which will be suspended from a scale so that you are about neck deep in water. The water will be about 82 to 85 degrees F. You will then tuck your knees up and bend your head forward so that you are completely submerged and blow as much air from your lungs as possible. You must try to remain in this position for 5 to 10 seconds before raising your head, to allow a scale reading to be made. These procedures will be repeated 6 to 10 times with rest intervals between each.

Arm and Leg Cranking for Cardiorespiratory Endurance (approximately 45 minutes)

Your maximal oxygen consumption and ventilatory threshold will be determined from a test which will involve simultaneous pedaling on a stationary bicycle and arm cranking at progressively increasing levels of resistance. Your expired air will be collected through a mouthpiece connected to rubber tubing. Your heart rate will be monitored by six electrodes attached to your chest wall. Following the measurement of a resting heart rate and blood pressure, you will begin pedaling and cranking against a light resistance at 60 rpm. Every three minutes the resistance will be increased in both the arms and the legs until you can no longer continue at the required pedaling speed of 60 rpm. The test will end when you indicate that you no longer wish to continue or your responses (heart function, respiration, and/or physical appearance) indicate that you should not continue or have reached your maximal effort. Following completion of this test, the resistance will be reduced so that you can recover comfortably.

Triathlon Performance Time

On August 28th, 1988 you will compete in the Bud Light Triathlon in San Jose. Your performance time for each portion as well as the overall race will be obtained.

Risks and Discomforts

Underwater Weighing:

The water quality in the tank is maintained daily, however there is the possibility of certain types of infection. This is very unlikely due to the daily chemical treatment and filtering of the water. Chlorine irritation, swallowing of water, and choking are also possible as in any pool situation. Discomfort associated with submersion

Bruises may result from these measurements, although very rarely does this occur. The pinching sensation from skinfold measurements may cause some discomfort.

Residual Lung Volume:

Some persons experience faintness and/or dizziness when performing the breathing procedures. Discomfort associated with this test may come from breathing through a mouthpiece with a noseclip in place.

Cardiorespiratory Endurance:

Some discomfort and dryness in the mouth, throat, and chest as a result of restricted breathing may occur. You

may feel lightheaded, fatigued, and slightly nauseous for a short time following this test. Also the discomforts commonly associated with exercise: sweating, increased heart rate, increased breathing rate, and elevated body temperature. At or near maximal exercise you may experience abnormal blood pressure, fainting and/or dizziness, muscle fatigue or cramps, and abnormalities in heart beat. If abnormalities are detected in pulmonary

Strength and Anaerobic Responses:

You may experience some muscle soreness and fatigue following these tests as well as increased heart rate, increased breathing rate, elevated body temperature, sweating, and fatigue during the test.

Benefits from Participation in Study

You will benefit from this study by receiving feedback on muscular strength, anaerobic work indices, body composition and size, and cardiorespiratory endurance characteristics. The study will benefit the population in general by identifying those physiological indices that differentiate between performance times in a triathlon.

Assurance of Confidentiality

The results of this investigation may be used for research publication and presentation. Your right to confidentiality will be protected unless your express consent is granted prior to the publication or presentation of the data.

Withdrawal from the Study

You may withdraw your consent and discontinue your participation in this study at any time (including during the testing) without prejudice. You may also decline to answer any question or item on the health history questionnaire.

Testing will be supervised and conducted by Dr. Craig J. Cisar, Certified Exercise Test Technologist and Carla M. Phillips. Certified CPR personnel will also be present during testing.

If you have any questions about the investigation now or during the testing, please feel free to ask. If additional questions come up later or in the case of an emergency, Carla M. Phillips (408) 295-2866 or Dr. Craig J. Cisar (408) 287-8132 will be happy to answer them. In the case of any complaints during or after the testing, you may contact Dr. Serena Stanford, Associate Academic Vice President of Graduate Studies and Research, at (408) 277-2943.

Consent

By signing this form, you are agreeing that:

- (a) you have decided to participate in this study having read the information provided above;
- (b) you understand the discomforts and risks involved;
- (c) you understand that you can withdraw at any time; and
- (d) you understand that your name will be kept confidential except with your express consent.

SIGNATURE _____ DATE _____

PRINT NAME _____

SIGNATURE OF WITNESS _____

SIGNATURE OF INVESTIGATOR _____

PRE-EXERCISE TESTING
HEALTH STATUS QUESTIONNAIRE

Date _____

Name _____ Occupation _____

Work or
Campus Address _____ Work or
Campus Phone _____

Home
Address _____ Home
Phone _____

Personal
Physician _____ Physician's
Phone _____

Age _____ yrs. Height _____ ft. Weight _____ Sex _____

Does the above weight indicate: a gain __, a loss __, no
change __ in the past year? How many pounds? _____

A. Joint-Muscle Status (Check areas in which you
currently have problems.

Joint Areas

- ☐ Wrists
- ☐ Elbows
- ☐ Shoulders
- ☐ Upper spine and neck
- ☐ Lower spine
- ☐ Hips
- ☐ Knees
- ☐ Ankles
- ☐ Feet
- ☐ Other _____

Muscle Areas

- ☐ Arms
- ☐ Shoulders
- ☐ Chest
- ☐ Upper back and neck
- ☐ Abdominal regions
- ☐ Lower back
- ☐ Buttocks
- ☐ Thighs
- ☐ Lower leg
- ☐ Feet
- ☐ Other _____

B. Health Status (Check if you previously or currently have any of the following conditions)

☐ High blood pressure	☐ Anemia
☐ Heart disease or dysfunction	☐ Hernias
☐ Peripheral circulatory disorder	☐ Thyroid
☐ Lung disease or dysfunction	dysfunction
☐ Arthritis or gout	☐ Pancreas
☐ Edema	dysfunction
☐ Epilepsy	☐ Liver dysfunction
☐ Multiple sclerosis	☐ Kidney
☐ High blood cholesterol or triglyceride levels	dysfunction
☐ Acute infection	☐ Neural
☐ Diabetes or blood sugar level abnormality	dysfunction
	☐ Others that you feel we should know about _____

C. Physical Examination History _____

Approximate date of your last physical examination _____

Physical problems noted at that time _____

When was the last time your resting electrocardiogram was evaluated? _____

Was it normal? Yes ☐ No ☐ If no, what was abnormal about it? _____

When was the last time you had your electrocardiogram evaluated during an exercise stress test? _____ What heart rate did you reach during this exercise? _____ Was the electrocardiogram normal? Yes ☐ No ☐ If no, what was abnormal about it? _____

Has a physician ever made any recommendations relative to limiting your levels of physical exertion? Yes ☐ No ☐ If yes, what limitations were recommended? _____

D. Current Medication Usage (List drug name and the condition being managed)

<u>Medication</u>	<u>Condition</u>
_____	_____
_____	_____
_____	_____

E. Physical Perceptions- Indicate any unusual sensations or perceptions. (Check if you have recently experienced any of the following during or soon after physical activity (PA); or during sedentary periods (SED)).

PA	SED		PA	SED	
☐	☐	Chest pain	☐	☐	Light headedness
☐	☐	Heart palpitations	☐	☐	Loss of balance
☐	☐	Unusually rapid breathing	☐	☐	Loss of coordination
☐	☐	Overheating	☐	☐	Extreme weakness
☐	☐	Muscle cramping	☐	☐	Numbness
☐	☐	Muscle pain	☐	☐	Mental confusion
☐	☐	Joint pain	☐	☐	Other _____
☐	☐	Nausea			

F. Family History (Check if any of your blood relatives- parents, brothers, sisters, aunts, uncles, and grandparents- have or had any of the following)

- ☐ Heart disease
- ☐ Heart attacks or strokes prior to age 50
- ☐ Elevated blood cholesterol or triglyceride level
- ☐ High blood pressure
- ☐ Diabetes

G. Current Habits (Check any of the following if they are characteristics of your current habits)

- ☐ Occupation is physically demanding
- ☐ Occupation is emotionally stressful and or hectic
- ☐ In your leisure, you regularly do manual garden or yard work
- ☐ In your leisure, you regularly go for long walks
- ☐ You frequently ride a bicycle
- ☐ You engage in an exercise program more than once per week. If so, what does this consist of? _____
- ☐ You smoke tobacco: ☐ cigarettes ☐ cigars ☐ pipe
_____ number per day (packs, cigars, or pipeful)

H. Triathlon Experience

- Years of triathlon experience _____
- Current weekly mileage: running _____
bicycling _____
swimming _____