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THE RELIABILITY OF THE SWIMMING ERGOMETER
IN OBTAINING VO_2 MAX OF MALE AND
FEMALE AGE-GROUP SWIMMERS

by

Thomas J. Meade, Jr.

An Abstract

of a thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in the School
of Health, Physical Education
and Recreation at
Ithaca College

September 1981

Research Thesis Advisor: Dr. A. Craig Fisher

ABSTRACT

This study was designed to test the reliability of the swimming ergometer in obtaining VO_2 max of male and female age-group swimmers.

The subjects (N=20) consisted of 9 males and 11 females who ranged in ages from 12 to 18 years and whose abilities as swimmers ranged from beginning competitive to elite.

The Rate of Perceived Exertion scale was used to assess ratings of perceived exertion upon completion of each work bout by each subject. Prior to testing, all anthropometric data were recorded as were environmental conditions.

All swimming work bouts during the two testing sessions were swum using the crawl stroke. A 500-yard warmup, swimming the crawl stroke, was swum prior to each testing session. Workload increments added to the swimming ergometer were selected according to the subject's caliber and training ability. All subjects reached VO_2 max during test and retest. Each work load lasted 3 minutes with expired air collected for the last 30 seconds. At the completion of each work load, the subject's post-exercise heart rate was taken.

VO_2 max was determined in liters per minute, milliliters per kilogram per minute, and milliliters per kilogram of lean body weight per minute. Maximal ventilation was determined in BTPS. Also determined were maximal heart rate and maximal O_2 pulse. An intraclass correlation coefficient was used to determine the reliability of these physiological variables.

The reliabilities for these physiological variables were (1)

for $\dot{V}O_2$ max l/min, .98 for males, females, and all subjects, (2) for $\dot{V}O_2$ max ml/kg/min, .90 for males, .96 for females, and .94 for all subjects, (3) for $\dot{V}O_2$ max ml/kg·lbw/min, .88 for males, .95 for females, and .91 for all subjects, (4) for VE max BTPS, .93 for males, .96 for females, and .95 for all subjects, (5) for O_2 pulse max, .95 for males, .88 for females, and .95 for all subjects and (6) for heart rate max, .38 for males, .45 for females, and .45 for all subjects.

It was felt that the low reliability of the maximal heart rate was due to human error in carotid palpation.

The use of the swimming ergometer to obtain $\dot{V}O_2$ max in age-group swimmers has proven highly reliable. The reliabilities for VE max and O_2 pulse max were also high. These high reliabilities show good reproducibility of using the swimming ergometer to test for $\dot{V}O_2$ max, VE max, and O_2 pulse of age-group swimmers.

THE RELIABILITY OF THE SWIMMING ERGOMETER
IN OBTAINING VO_2 MAX OF MALE AND
FEMALE AGE-GROUP SWIMMERS

A Thesis Presented to the Faculty
of the School of Health, Physical
Education, and Recreation
Ithaca College

In Partial Fulfillment of the
Requirements for the Degree
Master of Science

by
Thomas J. Meade, Jr.

September 1981

Ithaca College
School of Health, Physical Education and Recreation
Ithaca, New York

CERTIFICATE OF APPROVAL

MASTER OF SCIENCE THESIS

This is to certify that the Master of Science Thesis of
Thomas J. Meade, Jr.

submitted in partial fulfillment of the requirements
for the degree of Master of Science in the School of
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Chapter 1

INTRODUCTION

The results of the swimming events at the XXI Olympiad in Montreal have keenly reflected on the importance of exercise physiology in swimming. The Russians, East Germans, and Canadians have developed extensive research programs that have worked hand-in-hand with their swimmers and coaches. The United States, without government aid, has nevertheless done extensive research at the university and club level. It is imperative that readily available methods be used in testing swimmers, especially age-group swimmers.

Maximal oxygen uptake ($\dot{V}O_2 \text{ max}$) is one of the most important determining factors in analyzing fitness levels of swimmers. It is becoming more and more important in predicting athletic performance. It has become evident to exercise physiologists that to test a swimmer for $\dot{V}O_2 \text{ max}$, it should be done as specifically as possible to actual swimming (8, 10, 11, 19, 23, 27, 31, 36). This has resulted in the development of several types of swimming ergometry (10, 11, 27).

Many investigators have tested $\dot{V}O_2 \text{ max}$ of male college swimmers (21, 22, 23, 28, 30, 33). Fewer investigators have tested females (8, 18) and fewer yet have tested age-group male and female swimmers (18). To the author's knowledge, there have been no published results of $\dot{V}O_2 \text{ max}$ testing of male and female age-group swimmers using a swimming ergometer.

It is important, therefore, that an inexpensive, readily available method of testing $\dot{V}O_2 \text{ max}$ by using a swimming ergometer be made

available to the age-group swimming coach. $\dot{V}O_2$ max is one of the important predictors of success and knowing the $\dot{V}O_2$ max of swimmers can greatly benefit a coach in training his/her swimmers.

It is the aim of this study to examine the $\dot{V}O_2$ max of age-group swimmers through the use of the swimming ergometer (11) and to test for the reliability of the swimming ergometer for measuring $\dot{V}O_2$ max.

Scope of Problem

There are a few studies that have tested for $\dot{V}O_2$ max of age-group swimmers using a swimming flume or a swimming ergometer (21, 23). There are also studies that have tested $\dot{V}O_2$ max of age-group swimmers using bicycle or treadmill ergometers (15, 33, 38).

There have been only two studies (11, 28) that have tested for reliability of $\dot{V}O_2$ max of swimmers using a swimming ergometer. However, these studies used male college swimmers as subjects.

This investigator, in reviewing the literature, has found no evidence of studies done to test the reliability of the swimming ergometer to test for $\dot{V}O_2$ max in age-group swimmers.

Statement of Problem

This study was designed to test the reliability of the swimming ergometer in obtaining $\dot{V}O_2$ max of male and female age-group swimmers, using five varying work loads each lasting three minutes in duration. Each work load was followed by a five-minute rest period before the next began, with expired air collected for 30 seconds between two and one-half and three minutes. The work loads were progressively increased as the subjects swam in place.

Major Null Hypotheses

H_{0_1} : There will be no significant correlation between a test/retest of VO_2 max in liters per minute (l/min) on age-group swimmers using a swimming ergometer.

H_{0_2} : There will be no significant correlation between a test/retest of VO_2 max in milliliters per kilogram per minute (ml/kg/min) in age-group swimmers using a swimming ergometer.

H_{0_3} : There will be no significant correlation between a test/retest of VO_2 max in milliliters per kilogram of lean body weight per minute (ml/kg·lbw/min) in age-group swimmers using a swimming ergometer.

Minor Null Hypotheses

H_{0_1} : There will be no significant correlation between a test/retest of maximal heart rate (HR max) in age-group swimmers using a swimming ergometer.

H_{0_2} : There will be no significant correlation between a test/retest of maximal O_2 pulse in age-group swimmers using a swimming ergometer.

H_{0_3} : There will be no significant correlation between a test/retest of maximal ventilation (VE max) in age-group swimmers using a swimming ergometer.

Assumptions of Study

For the purpose of this study, the following assumptions have been made:

1. The mechanical efficiency of the swimming ergometer was not significantly different from test to test.
2. The subjects did not eat any food at least two hours before being tested.

Definition of Terms

The following terms are operationally defined for the purposes of this study:

1. Age-group Swimmers. Swimmers, male and female, between the ages of 12 and 18 years old who trained a minimum of five days a week at least two months before being tested.
2. Ratings of Perceived Exertion (RPE). This refers to a scale of numbers ranging from six to 20 (e.g., 19: "Very, very hard") used to indicate the subjective feelings of exertion while exercising (3).
3. Maximal Oxygen Uptake (VO_2 max). This refers to the highest oxygen consumption an individual can attain during physical work breathing air at sea level. The criterion that were used to determine when the maximum was reached were (1) an increase in workload with no increase in VO_2 , (2) a RPE of at least 17, and (3) a heart rate of at least 170.
4. BTPS. The body temperature, pressure, saturated with water.
5. STPD. The standard temperature, pressure, dry (0°C , 760 mm. Hg.).
6. Swimming Flume. A pool in which water can be circulated in a 2.5 meter wide and 1.25 meter deep, vertical loop by means of two horizontal, variable-pitch axial-flow pumps located in part of the loop beneath the 4 meter long test flume. The water flow rate can be varied and reproduced with great accuracy. Subjects can swim on the spot at various speeds in this test flume.
7. Swimming Ergometer. An apparatus that reliably regulates the energy requirements for swimming in water while the subject is

kept in a relatively stationary position (19).

Delimitations of Study

The delimitations of the study were as follows:

1. Only age-group swimmers (N=20) between the ages of 12 and 18 years from upstate New York were used as subjects for this study.
2. Only increments of one and/or two pounds were used in increasing the workloads to the maximal effort of the subject.
3. A discontinuous method for reaching $\dot{V}O_2$ max was used with a five-minute rest between workloads.
4. All subjects performed a warm-up of a 500-yard crawl stroke prior to each testing.
5. All subjects swam the crawl stroke with their face in the water for all testing.
6. A median of five workloads was performed by all subjects with the range being three to six workloads.
7. All submaximal workloads were performed for three minutes with expired air collected between two and one-half minutes to three minutes.
8. All maximal workloads were performed for at least one and one-half minutes up to three minutes with expired air collected for the last 30 seconds of the workload.
9. Upon the completion of each workload, Ratings of Perceived Exertion (RPE) and heart rate were recorded, with RPE being one of the determining factors for the number of workloads to be performed.
10. The percentage of body fat in the subjects was determined by the skinfold thickness method.

Limitations of Study

The limitations of the study were as follows:

1. The results of the study could only be inferred to age-group swimmers between the ages of 12 and 18 years of age.
2. Increments of the work loads other than those used may have resulted in different findings.
3. A rest period other than five minutes between workloads may have altered the findings.
4. The investigator was unable to control the environmental factors; (e.g., sleep, diet, daily exercise) of each subject, and these factors may have affected performance.
5. Tethered swimming, not free swimming, was used during the work bouts.

Chapter 2

REVIEW OF RELATED LITERATURE

The review of literature for the purposes of this study had its concentration in the following areas: (1) $\dot{V}O_2$ max, (2) $\dot{V}O_2$ max and swimmers, (3) $\dot{V}O_2$ max and age-group swimmers, (4) ergometry used to determine $\dot{V}O_2$ max, and (5) summary.

Maximal Oxygen Uptake ($\dot{V}O_2$ max)

$\dot{V}O_2$ max is the maximum volume of oxygen corrected to 0°C, 760 mm HG, Dry (STPD) that can be removed from the inspired air, while performing heavy work and is expressed in liters per minute (l/min). Gerber et al. (5:460) discussed various mediating variables affecting $\dot{V}O_2$ max:

After a maximum is reached the work may be continued using non-oxidative energy sources until the build-up of waste products forces a cessation. $\dot{V}O_2$ is dependent on the amount of active tissue in the body, so that the larger an individual is, the greater their $\dot{V}O_2$ is in terms of total body weight per minute (ml/kg/min). Also, the more muscle an individual has relative to body fat, the higher the $\dot{V}O_2$ values will be. Because of the relationship between muscle mass and $\dot{V}O_2$, $\dot{V}O_2$ is also described in terms of milliliters per kilogram of lean body weight per min. (ml/kg·lbw/min).

Wilmore (39) has shown a correlation ($r=.84$) between $\dot{V}O_2$ max (l/min) and endurance capacity. This finding adds validity to using $\dot{V}O_2$ max as an index of cardiovascular fitness and an indication of athletic performance.

Astrand and Rodahl (1) indicated that during prolonged exercise there is a high correlation between $\dot{V}O_2$ max and maximum aerobic capacity. The actual $\dot{V}O_2$ that is produced is only a percentage of the maximum

capacity and that percentage lowers as the work time is increased.

VO_2 max plays a primary role as a predictor of athletic performance. Costill and Winrow (14), in their studies on two middle-age ultramarathon runners, concluded that running efficiency, in terms of percent VO_2 max, can play an equal or greater role than aerobic capacity. Though aging lowers the aerobic capacity, these ultramarathon runners utilized 80-85 percent of their VO_2 max while nationally ranked distance runners employ only 75 percent of their VO_2 max during a marathon race.

Significant differences in VO_2 max between males and females, as pointed out by Gerber et al. (5) do not exist before the ages of 11 to 12 years. However, after this time, the females drop to 70 to 75 percent of the VO_2 max of males.

The standard criterion of VO_2 max is a failure of oxygen consumption to increase with a further increase in workload. It is important to be realistic in the reproductibility of these measurements while maintaining suitable levels of accuracy. Shephard (6:238) stated, "Individual readings for gas concentration and the like should have an absolute accuracy of one percent or better"; this implies measurement of O_2 to .03-.04 percent. The plateau level where O_2 consumption fails to increase is defined by Shephard (6:238) as "an increment in O_2 consumption of less than 2 ml/kg/min."

Taylor and Rowell (7) point out that a time period of from three to six minutes is used by most investigators to elicit VO_2 max, but that an intensity of work can be selected that will elicit a VO_2 max in 1.5 minutes.

Consolazio, Johnson, and Pecora (4) concluded in their examination of the effect of variables on VO_2 max that (1) room temperature

and a warm-up period influenced the VO_2 max, (2) an increase in muscle mass used, such as running and arm exercises simultaneously, showed a definite increase in VO_2 max, and (3) VO_2 max is maximal only for specified working conditions.

There are several physiological mechanisms which can play a role in VO_2 max. These are respiratory functions, cardiovascular functions involved in O_2 transportation to the active muscles and other factors affecting the capacity of the muscles to utilize O_2 .

The heart rate is probably used more as a predictor of VO_2 max than any other method. If direct cardiac measurements are not available, post-exercise heart rates may be used. McArdle, Zwiren, and Magel (32) stated that it is valid to use the post-exercise heart rate as a means of estimating heart rate during strenuous work if it is taken within the first 10 seconds upon completion of the work bout. The error is less than three percent.

There have been several investigators who have demonstrated the limitations of the prediction of VO_2 max from cardiac frequency measurements. Davies (16), Rowell, Taylor, and Wang (37), and Wyndham et al. (40), all have shown that a linear progression exists, at low rates of work, between VO_2 and cardiac frequency. However, as the work rates approach VO_2 max, the VO_2/HR curve becomes asymptotic in nature. Davies (16) thus concluded that if an accuracy greater than ± 15 percent is required, there is no alternative but to directly measure VO_2 max.

Kaijser (25), in discussing the limiting factors for aerobic capacity, found that there was no significant decrease in arterial oxygen saturation during exhaustive exercise and, therefore, pulmonary function cannot possibly be a limiting factor for aerobic work capacity.

There have been several investigators who have tested the reliability of VO_2 max. Bar-or and Swiren (9) tested for the reliability and validity of VO_2 max during arm exercise. Though their reliability was high ($r=.94$) their validity coefficient was only .74. These findings indicated that individuals repeatedly used the same muscles and reached an all-out stage. However, some individuals are aided, to different degrees, by their trunk and leg muscles. This lowers the validity of this test as a predictor of aerobic capacity.

Moncrieff (34) tested the reliabilities of VO_2 max to several variables. Correlations were as follows: body weight ($r=.63$), active tissue ($r=.91$), fat-free body ($r=.85$), weight adipose tissue ($r=.75$), hemoglobin content ($r=.94$), hemoglobin content when fat-free body ($r=.25$), and blood volume ($r=.78$).

VO_2 max and Swimmers

The VO_2 max of swimmers is best tested by a swimming ergometer or flume over the use of a treadmill or bicycle ergometer. This is illustrated in Table 1 where a significant difference is seen between VO_2 max scores of swimmers tested by a treadmill compared to a flume or tethered swimming.

Shephard (6) found that girl swimming champions tested on a swimming ergometer reached only 92 percent of their VO_2 max recorded using a bicycle ergometer. He attributed the lower swimming VO_2 max to an increased thoracic pressure, a more localized muscle involvement, and a horizontally supported position causing less strain on the heart.

Astrand and Rodahl (1) found that the quotient of pulmonary ventilation to VO_2 was significantly lower during maximal swimming than

Table 1

Physiological Data on Swimmers
A Review of the Literature

	N	Age	Sex	Ht(cm)	Wt (kg)	Training Level	Ergo- meter	VE	VE max	VO ₂ max l/min	VO ₂ max ml/kg/ min	HR max	max O ₂ Pulse
Cummingham and Eymon (15)	28 19	14 13	M F	163 159	54 49	T T	B B	88.9* 64.1	30.3* 30.4	2.94 2.11	54.2 43.8	189 190	15.6 11.1
Dixon and Faulkner (17)	6 6 6 6	19 19 26 26	M M M M	181 181 178 178	74 74 73 73	T T U U	Tm Td Tm Td	102.5** 100.9 110.8 93.8	24.1** 24.9 30.9 26.2	4.26 4.05 3.58 2.66	57.6 54.7 49.0 36.4	- - - -	- - - -
Holmer (21)	12 12	15 15	F F	165 165	54 54	T T	Tm F	114.0** 83.0	36.0** 28.0	3.17 2.96	58.7 54.8	194 182	16.3 16.3
Holmer, Lundin, and Eriksson (23)	12 12 11 11	19 19 17 17	M M F F	184 184 170 170	78 78 66 66	E E E E	Tm F Tm F	182.3** 152.1 132.6 103.1	33.9** 30.1 36.4 29.1	5.38 5.05 3.64 3.42	68.6 64.7 55.3 51.8	199 184 201 186	27.0 27.4 18.1 18.4
Holmer et al. (24)	5	25	M	180	69	UE	Tm	154.2**	34.4**	4.54	65.8	186	24.4
"	5	25	M	180	69	UE	F	111.0	29.8	3.79	54.9	174	21.8
Kanitz (26)	9 9	21 20	M M	181.5 181.4	78.5 77.6	TW TS	Tm Tm	127.5** 127.9	- -	4.66 4.87	59.3 62.8	194 202	- -
Magel (27)	26 26	20 20	M M	181 181	77 77	T T	Tm Td	122.2* 104.5	29.1* 25.2	4.20 4.14	55.5 55.0	197 185	21.3 22.4
Magel et al. (30)	30 30	22 22	M M	177 177	75 75	U U	Tm Td	163.9** 127.4	40.2** 36.7	4.08 3.47	54.9 46.7	198 184	20.6 18.8
McArdle et al. (31)	5 5	19 19	M M	183 183	77 77	T T	TmW FS	- -	- -	3.83 3.36	49.8 43.8	190 169	20.1 19.9
Miyashita, Hayashi, and Furuhashi (33)	20 13	20 14	M F	170 164	70 59	T T	Tm Tm	128.0* 75.7	29.4* 25.9	4.36 2.92	62.4 49.3	- -	- -
Sprynarova and Parizkova (38)	10	10	F	166	64	T	Tm	100.7*	34.5*	2.92	49.0	191	15.3

Training Level: T=Trained
U=Untrained
E=Elite

UE=Untrained Elite
TW=Trained Waterpolo
TS=Trained Swimming

Ergometer Used: B=Bicycle
Tm=Treadmill
Td=Tethered

F=Flume
TmW=Treadmill-Walk
FS=Free Swimming

* STPD
**BTPS

during cycling (27.7 and 35.5). They felt the reason for this relative hypoventilation may be the different mechanical conditions for breathing.

Holmer (21), in a study on 12 girl swimmers using a swimming flume, found that $\dot{V}O_2$ max, maximal pulmonary ventilation, and maximal heart rate were significantly lower in swimming than in running (treadmill) or cycling (bicycle ergometer), respectively.

Researchers Dixon and Faulkner (17), using tethered swimming and treadmill running, found no significant difference in $\dot{V}O_2$ max in six trained swimmers. However, in six recreational swimmers the swimming $\dot{V}O_2$ max was 25 percent lower than running.

Holmer et al. (24), testing five male subjects for $\dot{V}O_2$ in running and swimming, found $\dot{V}O_2$ max to be 15 percent lower during swimming. Also, maximum heart rate was seven percent lower during swimming.

Magel (27) attributed the lower cardiac response, shown by several authors in Table 1, to the change in body position from the upright to the prone or supine position while swimming.

Holmer (20), in studying elite swimmers found that $\dot{V}O_2$ max during swimming was six to seven percent lower than in running, and approximately the same as in cycling. Corresponding values for untrained swimmers were 20 percent and 10 percent lower, respectively.

In examining Table 1, the $\dot{V}E$, $\dot{V}E$ max, $\dot{V}O_2$ max in l/min and ml/kg/min, and maximum heart rate data of studies (17, 21, 23, 24, 27, 30, 31), using both the treadmill and either tethered swimming, the flume, or free swimming, show that these scores are significantly higher for running than swimming. Holmer (20) noted that $\dot{V}O_2$ max during running cannot be employed to predict performance in swimming, because efficiency in stroke may play a greater role in predicting performance

than VO_2 max.

Magel and McArdle (29), in their conclusion, stated that the level of training and the specificity of exercise appear to influence the VO_2 max in certain environments. It is more desirable to obtain VO_2 max data during swimming than during bicycling or running in order to assess accurately the swimmer's ability to perform maximally while swimming.

Magel et al. (30) tested the specificity of swim training on VO_2 max by having 15 male recreational swimmers undergo an interval training program over a 10-week period, while 15 control subjects did not participate in any form of training. The experimental swimmers significantly increased their swimming VO_2 max (380 ml/min) and significantly decreased their maximal heart rate. However, there was not a significant improvement in VO_2 max when the subjects were retested, using the treadmill running test.

Kanitz (26), in an effort to show that VO_2 max is increased equally in water polo training as in a pre-season swim training program, tested for VO_2 max by treadmill running. He concluded that "the improvement of maximum aerobic capacity due to water polo training appears to be as good as the improvement due to pre-season swim training" (26:37). However, several researchers (17, 21, 23, 24, 27, 30, 31) have pointed out that Kanitz's results would probably have been different if a more specific swimming ergometer was used.

Costill (12) tested the effects of water temperature on VO_2 max. He used three swimming pool water temperatures (64^o, 77^o, and 90^oF) and found that heart rates and VO_2 max values were not significantly changed at either temperature.

The reliability of tethered swimming in testing $\dot{V}O_2$ max has been shown to be quite good. Magel and Faulkner (28), using 26 highly trained college swimmers in a test-retest of $\dot{V}O_2$ max using tethered swimming, showed a correlation of .93 and the lack of a significant difference with a paired t-analysis indicated good reproducibility.

Holmer (20), in a study of male elite swimmers, compared $\dot{V}O_2$ in relation to swimming speed of the four competitive strokes. He found that $\dot{V}O_2$ in the front crawl and backstroke appeared to display an exponential increase as swimming speed increases, while the increase of $\dot{V}O_2$ during breaststroke and butterfly was linear or less at high speeds. Front crawl and backstroke reach a higher $\dot{V}O_2$ probably because there is more continuous propulsion.

$\dot{V}O_2$ max and Age-Group Athletes

In examining studies on age-group swimmers, there have been very few that have tested males and females both for $\dot{V}O_2$ max using swimming ergometry.

A review of literature on the $\dot{V}O_2$ max values of females in different sports was done by Gerber et al. (5). They found the average young untrained female in America has a $\dot{V}O_2$ max of 31.9 ml/kg/min compared to a 38.0 ml/kg/min of European women. However, for sportswomen, the scores, American to European, were 50.8 to 50.6 ml/kg/min, respectively. Gerber et al. (5) reported on two studies that recorded $\dot{V}O_2$ max scores of 11 to 13 year old girls (track) as 52.5 and 55.4 ml/kg/min. They also reported on four studies for girls (track) whose ages ranged from 13 to 18 years. The scores for $\dot{V}O_2$ max reported were 44.2, 47.8, 48.5 and 49.4 ml/kg/min. This illustrates how additional body fat gains

made during puberty will decrease $\dot{V}O_2$ max (ml/kg/min) for post-pubescent females as body fat is not an active O_2 consuming tissue.

Holmer (21) tested 12 girl swimmers age 13-18 years for $\dot{V}O_2$ max during swimming (flume) and treadmill running. The mean $\dot{V}O_2$ max value during running was 3.17 l/min while the mean value for swimming was 2.96. In terms of speed and $\dot{V}O_2$ max, Holmer found the front crawl stroke proved to be the most economical for testing purposes.

The only study using both male and female age-group swimmers, done by Cunningham and Eynon (15), used a bicycle ergometer to determine $\dot{V}O_2$ max. For the study, 43 (19 girls, 24 boys) competitive swimmers, 10-16 years of age, were used. The mean $\dot{V}O_2$ max value for the girls was 43.8 ml/kg/min, while the boys' value was 54.2 ml/kg/min. In comparing these values with those of a relatively elite group of 22-year old competitive swimmers, the younger athletes had similar $\dot{V}O_2$ max values (ml/kg/min). The authors concluded that the development of speed and endurance in outstanding swimmers appears to be primarily dependent upon the maintenance of aerobic capacity established in early pre-pubertal growth years and the subsequent development of strength, swimming skill, and capacity for anaerobic metabolism as the young swimmer matures.

Sprynarova and Parizkova (38) recorded the $\dot{V}O_2$ max of 10-girl gymnasts and 10 girl swimmers as 42.5 and 45.9, ml/kg/min, respectively, using a running treadmill. Thus, the group of swimmers had significantly higher values of absolute oxygen consumption than the group of gymnasts, however when calculated per kg/body weight, the difference between the groups disappeared.

Eklom (18) tested the effect of physical training in adolescent

boys. Six boys, all 11 years of age, were studied before and after six months of training. A group of seven nontraining boys of the same age was studied at the same time. The VO_2 max of the training group improved from 2.15 to 2.48 l/min, a change of 15 percent, while there was no change in the control group. Five boys from the training group continued training for another 26 months. Their VO_2 max l/min at the end of this period had increased in total by 55 percent.

Astrand et al. (8) tested 30 top Swedish girl swimmers aged 12 to 16 years and reported a mean VO_2 max value of 3.8 l/min using the bicycle ergometer. They found that, in girls, development during early adolescence normally leads to a great increase in the aerobic capacity; from 1.7 l/min in 10- to 11-year olds to 2.6 l/min in 14- to 15-year olds. In relation to the body weight, the VO_2 max decreases by an average 12 percent if the older girls are compared to the younger ones. However, in boys, there are successive marked increases in VO_2 max until 18 years of age. The authors concluded that girls have far greater prospects than boys of being prominent, at an early age, in sport events that make large demands on oxygen transporting organs.

Holmer (20) reported on two teenage identical twin sisters who were taking part in intensive physical training other than swimming. The two sisters displayed the same VO_2 max in running, but the one who participated in hard swim training displayed a 24-29 percent higher VO_2 in different swimming styles than her sister who was not specially trained by swimming. Results from this study suggest that it is swim training which produces the main performance improvement in swimming.

Ergometry Used to Determine VO_2 max

The type of ergometer that is used to determine VO_2 max is very

important because of the specificity it must have to the true muscle tissues used in a specified activity. If a specific ergometer is used, then true $\dot{V}O_2$ max can be achieved.

Gleser, Horstman, and Mello (19) performed tests to determine whether combined arm and leg work results in a $\dot{V}O_2$ greater than the $\dot{V}O_2$ max obtained using leg work alone. Their results showed that adding arm work to maximal leg work increases $\dot{V}O_2$ max by an average of 10 percent and that this is about what would be expected from the additional working muscle mass. The results were not due to training of the subjects as legs-only $\dot{V}O_2$ max repeated after the combined exercise did not differ from legs-only $\dot{V}O_2$ max measured before the combined exercise. These results are in direct opposition to arguments used to support the hypothesis that cardiac output limits $\dot{V}O_2$ max.

Reybrouck, Heigenhauser, and Faulkner (36) studied the effects of arm, leg, and combined arm-leg ergometry on the $\dot{V}O_2$ and cardiac output. Three healthy males were subjects. The $\dot{V}O_2$ max in arm ergometry averaged 68 percent of the $\dot{V}O_2$ max in leg ergometry and 60 percent of $\dot{V}O_2$ max in combined arm-leg ergometry. Two subjects with $\dot{V}O_2$ max's less than 45 ml/kg/min had a mean $\dot{V}O_2$ max in combined arm-leg ergometry 19 percent higher than in leg ergometry. A third subject, with a $\dot{V}O_2$ max greater than 50 ml/kg/min, showed no change. The authors concluded that skeletal muscle blood flow appears to be a critical factor in the limitation of $\dot{V}O_2$ max in arm or leg ergometry.

Magel (27) conducted a study comparing the physiologic response to a progression of work task during treadmill running and tethered swimming. The subjects were 26 highly trained college swimmers. The results showed significantly lower cardiac response (heart rate/ $\dot{V}O_2$ max)

during swimming, which can probably be attributed to the change in body position from the upright to the prone or supine position while swimming as well as to the more favorable conditions for heat dissipation during work in water as compared to work in air. Prone swimmers also experience a relative hypoventilation due to the limitation in breathing pattern imposed by stroke mechanics, which results from a lowered tidal volume.

Holmer and Astrand (22) reported on a new swimming ergometer. The ergometer is a swimming flume in which the water can be circulated in a 2.5 meter wide and 1.2 meter deep vertical loop by two horizontal, variable pitch, axial-flow pumps. These are located in the part of the loop below a test basin, which is 4.0 meters long. The speed can be varied and reproduced with great accuracy. In this channel the subjects can swim at various speeds while remaining in the same spot.

Bjorkman (10:122) noted the value of an aquatic (flume) treadmill, stating, "It enables swimmers to practice their stroke, style, speed, and breathing, while at the same time permitting trainers to detect and analyze swimming faults and physiological and medical experts to measure physical reactions."

Costill (11) tested 13 male collegiate swimmers for reliability of $\dot{V}O_2$ max on a tethered swimming ergometer. Two trials were administered on consecutive days to determine the reliability of the energy requirements to perform the selected task. The results showed that a significantly high reliability coefficient was found for the volume of oxygen consumed during the third minute of exercise. The mean $\dot{V}O_2$ max values of T_1 and T_2 were 2.47 l/min and 2.49 l/min, respectively, with a correlation of .915. Costill concluded that (1) exercise requirements

imposed on a subject in water can be regulated while he is maintained in a stationary position, and (2) the swimming ergometer was found to be a reliable instrument for controlling the exercise requirements in the water.

Costill (13) tested the energy requirements during exercise in the water. He noted that while a thermal difference may exist at rest in water, the energy requirements and heart rates recorded during submaximal and maximal work in water temperatures ranging from 17.4^o-33.1^oC are not significantly different at any given work intensity. Using a modified cycling ergometer, Costill demonstrated that water substantially reduces the working efficiency by approximately 4.0 to 5.7 percent. Heart rate responses and energy requirements were compared among sitting-land, supine-land, prone-water, and supine-water during submaximal and maximal cycling exercise. The maximal workloads, $\dot{V}O_2$ max, and maximal heart rate achieved by men exercising in water were significantly lower than those recorded on land.

Summary

Several studies (1, 14, 39) have shown that while there is a high correlation between $\dot{V}O_2$ max and aerobic capacity, $\dot{V}O_2$ max does not necessarily play the primary role in prediction of athletic performance. Costill and Winrow (14) have shown in studies on two middle-aged ultramarathon runners that running efficiency plays a greater role in predicting athletic performance than aerobic capacity.

There are several physiological mechanisms which can play a role in $\dot{V}O_2$ max. They are respiratory functions, cardiovascular functions involved in O_2 transportation to the active muscles, and other factors

affecting the capacity of the muscle tissues to utilize O_2 .

While there are several studies that have tested the relationship of VO_2 max to different variables (9, 25, 35), prediction of VO_2 max from these variables has not been successful. The variable with the highest correlation has proven to be the heart rate. Several investigators (16, 37, 40) have shown that a linear progression exists, at low rates of work, between VO_2 and cardiac frequency. However, as the work rates approach VO_2 max, the VO_2 /heart rate curve becomes asymptotic in nature. It has been concluded that if a VO_2 max accuracy of ± 15 percent is required, direct measurement of VO_2 max should be done (16).

Table 1 in the review of literature clearly shows the relationship between VO_2 max and swimmers. It may be concluded from this table that it is more desirable to obtain swimmers VO_2 max data during swimming than during bicycling or running in order to assess accurately the swimmers' ability to perform maximally while swimming.

Costill (12) showed that water temperature (64° , 77° , and 90° F) had no significant affect on VO_2 max values of swimmers.

There have been several studies on age-group athletes and VO_2 max (5, 8, 15, 18, 21, 38). The conclusions drawn are summarized as follows: (1) aerobic training in age-group boys will significantly increase VO_2 max (15, 18), (2) girl swimmers compared to other girl athletes need specific aerobic swim training to improve their swimming VO_2 max (20, 21, 38), and (3) girls have far greater prospects than boys of being prominent, at an early age, in sports events that make large demands on oxygen transporting organs (8).

Several authors (10, 11, 19, 22, 27, 36) have concluded that ergometry used to test $\dot{V}O_2$ max in sports should be specific to that individual sport to be reliable and valid.

Chapter 3

METHODS AND PROCEDURES

The following is a review of the methods and procedures employed in this study. The review has been divided into six areas: (1) selection of subjects, (2) testing instruments, (3) methods of data collection, (4) scoring of data, (5) treatment of data, and (6) summary.

Selection of Subjects

This study was conducted in the summer of 1976. The subjects were selected from the Ithaca YMCA and Ithaca Aquatics swimming teams. The subjects (N=20) consisted of nine males and 11 females who ranged in ages from 12 to 18 years and whose abilities as swimmers ranged from beginning competitive to elite. The training characteristics of the subjects are listed in Tables 2 and 3. There were 22 subjects asked to volunteer of which 20 agreed to do so. The two subjects who were not tested were willing, but time commitments prevented them from participating. The physiological and anthropometric characteristics of the subjects are presented in Tables 4, 5, 6 and 7.

Testing Instruments

There were several testing instruments used in this study and they will be described below. The percentage of body fat was determined by skinfold thickness calipers, while height and weight were determined by spring scales.

Table 2

The Training Characteristics of Female
Age-Group Swimmers (N=11)

Subjects	Age	Yrs of Training	Yds/Day*	Days/Wk*	Mo/Yr*	Event & Best Time (Yds)	VO ₂ max STPD ml/kg/min	
							T ₁	T ₂
JL	15	6	5,000	6	9	100FR 1:01.0	39.9	41.9
ND	18	5	4,500	5	12	100FR :57.6	60.6	59.4
EL	13	4	5,000	5	9	100FR 1:04.0	41.5	41.0
JS	16	4	5,000	5	8	100FR 1:01.5	44.0	48.9
LA	12	5	5,000	5	10	100FR 1:04.2	51.6	52.9
CM	14	5.5	5,500	6	12	100FR :59.8	51.8	53.1
DD	14	1	4,000	5	12	100FR 1:08.0	53.2	51.4
CD	15	6	8,000	6	11	100FR :56.9	60.6	60.9
JT	14	6	6,000	6	9	100FR 1:01.1	44.6	47.9
JD	15	7	8,000	6	11	100FR :55.5	58.5	54.3
LC	15	4	6,000	6	9	100FR 1:03.2	50.4	53.2

*Past Year

Table 3
The Training Characteristics of Male
Age-Group Swimmers (N=9)

Subjects	Age	Yrs of Training	Yds/Day*	Days/Wk*	Mo/Yr*	Event & Best Time (Yds)	VO ₂ max STPD ml/kg/min	
							T ₁	T ₂
KD	18	15	10,000	6	12	100FR :48.8	58.0	55.8
JM	16	2	5,000	4	9	100FR :58.0	52.9	53.5
DS	18	10	10,000	6	12	100FR :48.1	59.5	59.7
PD	12	5	5,000	6	12	100FR :59.4	61.7	57.5
KM	17	9	10,000	6	9	100FR :47.8	69.6	62.4
BR	15	4	5,000	6	9	100FR :57.6	52.9	53.1
JA	16	5	10,000	6	9	100FR :48.2	54.8	59.2
BW	13	3	4,000	5	9	100FR 1:04.0	51.2	50.6
RS	14	1	4,000	5	3	100FR 1:07.2	49.7	44.5

*Past Year

Table 4

The Anthropometric Characteristics of Female
Age-Group Swimmers (N=11)

Subjects	Age	Ht(cm)	Wt(kg)		B.S.A.		%Fat	LBW(kg)		Fat BW(kg)	
	T ₁	T ₁	T ₁	T ₂	T ₁	T ₂	T ₁	T ₁	T ₂	T ₁	T ₂
JL	15	166.4	63.6	63.2	1.71	1.72	24.8	47.9	47.5	15.8	15.7
ND	18	157.5	56.5	54.9	1.56	1.55	18.4	46.1	44.8	10.4	10.1
EL	13	164.5	50.2	49.7	1.54	1.53	21.1	39.6	39.2	10.6	10.5
JS	16	179.1	77.3	75.7	1.96	1.95	25.7	57.4	56.2	19.9	19.5
LA	12	170.2	58.2	58.1	1.70	1.70	21.8	45.5	45.4	12.7	12.6
CM	14	172.7	60.8	60.8	1.74	1.74	16.8	50.6	50.6	10.2	10.2
DD	14	162.6	55.2	54.7	1.59	1.58	19.5	44.5	44.0	10.8	10.7
CD	15	165.1	52.6	51.9	1.57	1.57	17.3	43.5	43.0	9.1	9.0
JT	14	162.6	49.6	48.9	1.52	1.51	17.0	41.1	40.6	8.4	8.3
JD	15	167.6	56.3	56.6	1.64	1.64	16.6	46.9	47.2	9.3	9.4
LC	15	169.5	63.9	63.4	1.74	1.74	22.2	49.7	49.3	14.2	14.1

Table 5

The Anthropometric Characteristics of Male
Age-Group Swimmers (N=9)

Subjects	Age	Ht(cm)	Wt(kg)		B.S.A.		%Fat	LBW(kg)		Fat BW(kg)	
		T ₁	T ₁	T ₂	T ₁	T ₂		T ₁	T ₂	T ₁	T ₂
KD	18	186.7	80.6	79.8	2.06	2.06	10.9	71.8	71.1	8.8	8.7
JM	16	171.5	67.2	67.2	1.79	1.79	19.7	53.9	53.9	13.3	13.3
DS	18	189.2	80.1	77.5	2.09	2.05	10.9	71.4	69.1	8.7	8.5
PD	12	157.5	54.3	53.6	1.54	1.54	18.3	43.9	43.4	10.4	10.3
KM	17	178.4	64.2	63.6	1.83	1.81	16.3	53.7	53.3	10.5	10.4
BR	15	171.5	71.0	71.3	1.84	1.84	19.1	57.5	57.6	13.6	13.6
JA	16	179.7	69.8	70.9	1.89	1.90	15.4	59.0	60.0	10.7	10.9
BW	13	149.9	43.0	42.7	1.34	1.34	15.8	36.2	36.0	6.8	6.8
RS	14	168.3	54.1	54.0	1.62	1.62	21.0	42.7	42.6	11.4	11.3

Table 6

The Physiological Characteristics of Female
Age-Group Swimmers (N=11)

Subjects	VE max BTPS Min Vol (l) x 100		VO ₂ max STPD l/min		VO ₂ max ml/kg/min		VO ₂ max ml/kg·lbw/min		O ₂ Pulse max ml/min ÷ HR		Heart Rate max B/min	
	T ₁	T ₂	T ₁	T ₂	T ₁	T ₂	T ₁	T ₂	T ₁	T ₂	T ₁	T ₂
JL	73.8	70.5	2.54	2.65	39.9	41.9	53.1	55.8	15.1	17.0	168	156
ND	81.4	83.1	3.42	3.26	60.6	59.4	74.2	72.8	21.9	20.1	156	162
EL	48.2	50.4	2.06	2.06	41.5	41.0	52.6	52.0	12.7	14.3	162	144
JS	97.1	89.2	3.40	3.70	44.0	48.9	59.2	65.8	20.2	22.0	168	168
LA	94.0	92.6	3.00	3.07	51.6	52.9	65.9	67.6	20.8	17.6	144	174
CM	79.0	88.0	3.15	3.23	51.8	53.1	62.3	63.9	19.4	17.9	162	180
DD	88.0	76.2	2.94	2.81	53.2	51.4	66.1	63.9	17.5	15.6	168	180
CD	83.8	82.5	3.19	3.16	60.6	60.9	73.3	73.5	19.0	18.8	168	168
JT	50.2	50.7	2.21	2.34	44.6	47.9	53.7	57.7	14.7	15.0	150	156
JD	84.7	75.8	3.29	3.07	58.5	54.3	70.1	65.0	17.7	16.5	186	186
LC	86.7	86.0	3.22	3.37	50.4	53.2	64.8	68.3	21.5	19.4	150	174

Table 7

The Physiological Characteristics of Male
Age-Group Swimmers (N=9)

Subjects	VE max BTPS Min Vol (l) x100 O ₂ Con. (ML)		VO ₂ max STPD l/min		VO ₂ max ml/kg/min		VO ₂ max ml/kg·lbw/min		O ₂ Pulse max ml/min÷HR		Heart Rate max B/min	
	T ₁	T ₂	T ₁	T ₂	T ₁	T ₂	T ₁	T ₂	T ₁	T ₂	T ₁	T ₂
KD	112.0	107.2	4.67	4.45	58.0	55.8	65.1	62.6	31.1	30.9	150	144
JM	95.3	113.1	3.55	3.59	52.9	53.5	65.9	66.6	21.9	18.7	162	192
DS	113.7	110.2	4.77	4.63	59.5	59.7	66.8	67.1	26.5	26.6	180	174
PD	79.7	70.3	3.35	3.09	61.7	57.5	76.3	71.2	20.7	17.8	162	174
KM	107.2	91.1	4.47	3.97	69.6	62.4	83.2	74.5	25.7	23.6	174	168
BR	90.2	84.1	3.76	3.78	52.9	53.1	65.4	65.6	26.1	21.7	144	174
JA	91.7	92.0	3.82	4.20	54.8	59.2	64.7	70.0	19.9	24.1	192	174
BW	60.9	58.8	2.20	2.16	51.2	50.6	60.8	60.0	12.2	12.9	180	168
RS	77.3	77.9	2.69	2.40	49.7	44.5	63.0	56.3	14.0	13.6	192	176

A modified version of Costill's (11) swimming ergometer was used (Figures 1 and 2). The ergometer consists of a plastic coated 1/8-inch wire cable, connecting the weight or force of the ergometer to the adjustable belt worn by the subject. The cable was split to a one-inch by three-foot dowel and then comes together at the belt. This was done to allow for free leg movement. The only force exerted on the swimmer is straight back from the hips. This is the same force as the weight attached to the cable.

Wet and dry bulb thermometers were used to determine air and water temperature, and humidity. A standard mercury column barometer was used to determine barometric pressure.

The expired gas collection system consisted of several integral parts. A double hose regulator was disassembled and the intake-outtake hose, mouth piece, and two one-way valves were used as the breathing apparatus attached to the subjects. This, in turn, was connected by a pliable plastic ribbed one-inch diameter hose to a 120-liter Tissot gasometer. Expired air for analysis was collected at the intake valve of the Tissot gasometer with a 100-milliliter syringe and rechanneled into heat sealed, plastic coated, aluminum 500-milliliter air bags.

The gases were analyzed using the Beckman F₂-O₂ analyzer, the Beckman LB-2-CO₂ analyzer, and the Beckman microcatheter sample pump.

A three-foot diameter pace clock with a 60-second sweep was used for all timing purposes.

The six to 20 RPE scale (3) was used to provide the rating of perceived exertion. The scale consists of 13 numbers from six to 20,

where every other number has an attached verbal expression (Appendix A).

Methods of Data Collection

All swimming work bouts took place using the swimming ergometer pictured in Figures 1 and 2. The swimming ergometer was used in a pool, with a depth of four feet at the work site and with the closest side being seven feet away.

The data were collected during two testing sessions. At the first testing session, the subjects' height, weight, age, and skinfold thickness tests were taken and recorded on the Data Collection Sheet (Appendix B). Also, the training characteristics of the subjects were recorded on the data collection sheet. At the second testing session only the weight of the subject was recorded again.

The subjects were then shown the swimming ergometer and instructed in its use. These instructions are listed in Appendix C. All subjects viewed the swimming ergometer in use before they were tested (Figure 3).

Prior to their warm-up, each subject was read the instructions for the Rate of Perceived Exertion (Appendix D) developed by Borg (3), and shown the RPE chart they would be looking at, at the end of each work bout. During the test trials, the subjects were asked to rate their exertion at the completion of each work bout.

The timing of all workloads, rest intervals, and gas collection was accomplished by use of a large 60-minute pace clock with a 60-second sweep hand.

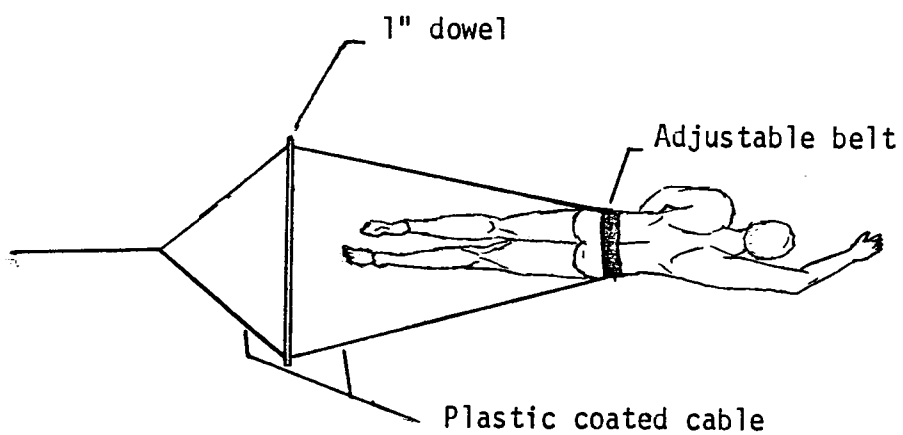


Figure 1
Overhead View of Swimming
Ergometer

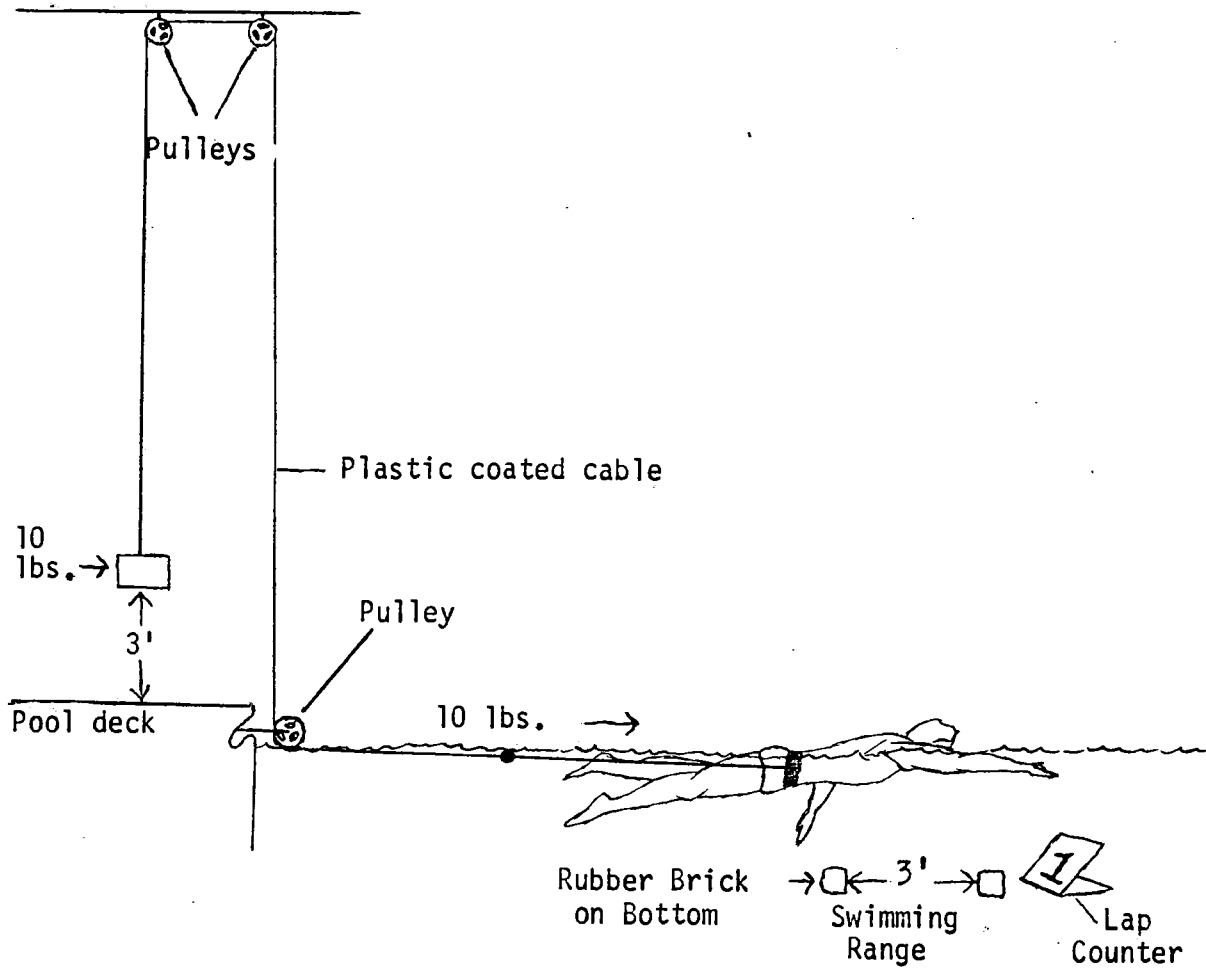


Figure 2
Side View of Swimming
Ergometer

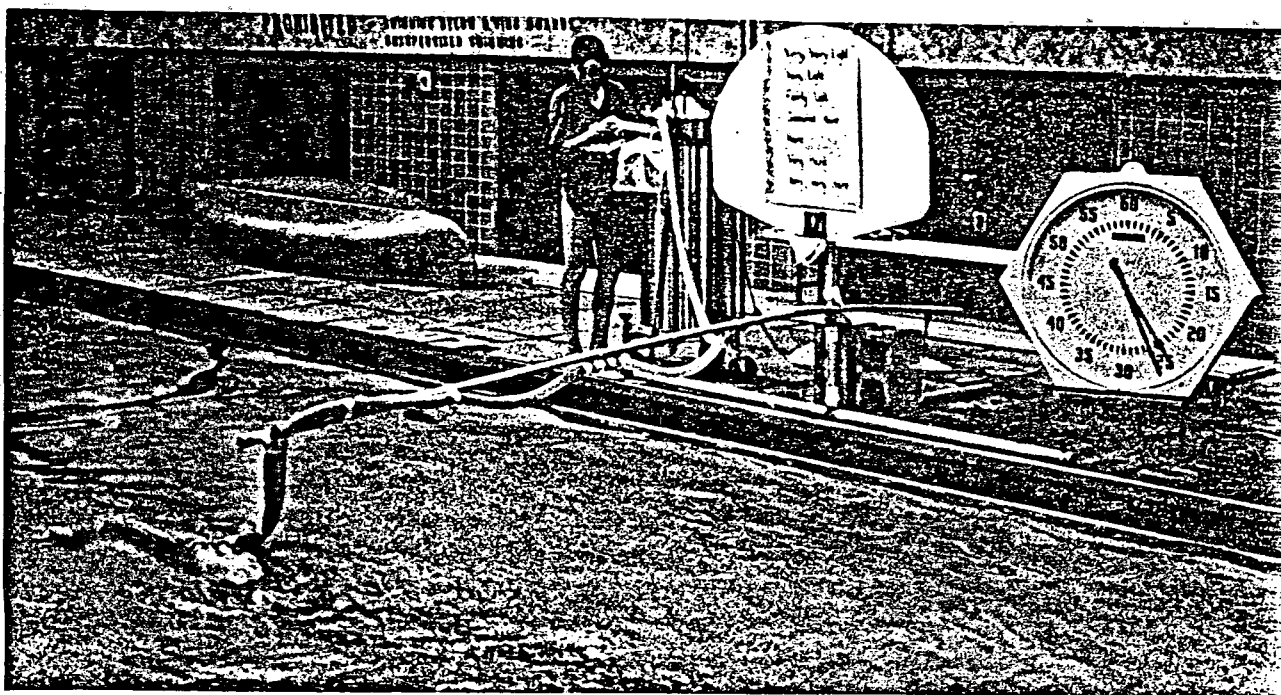


Figure 3

View of a Swimming Ergometer

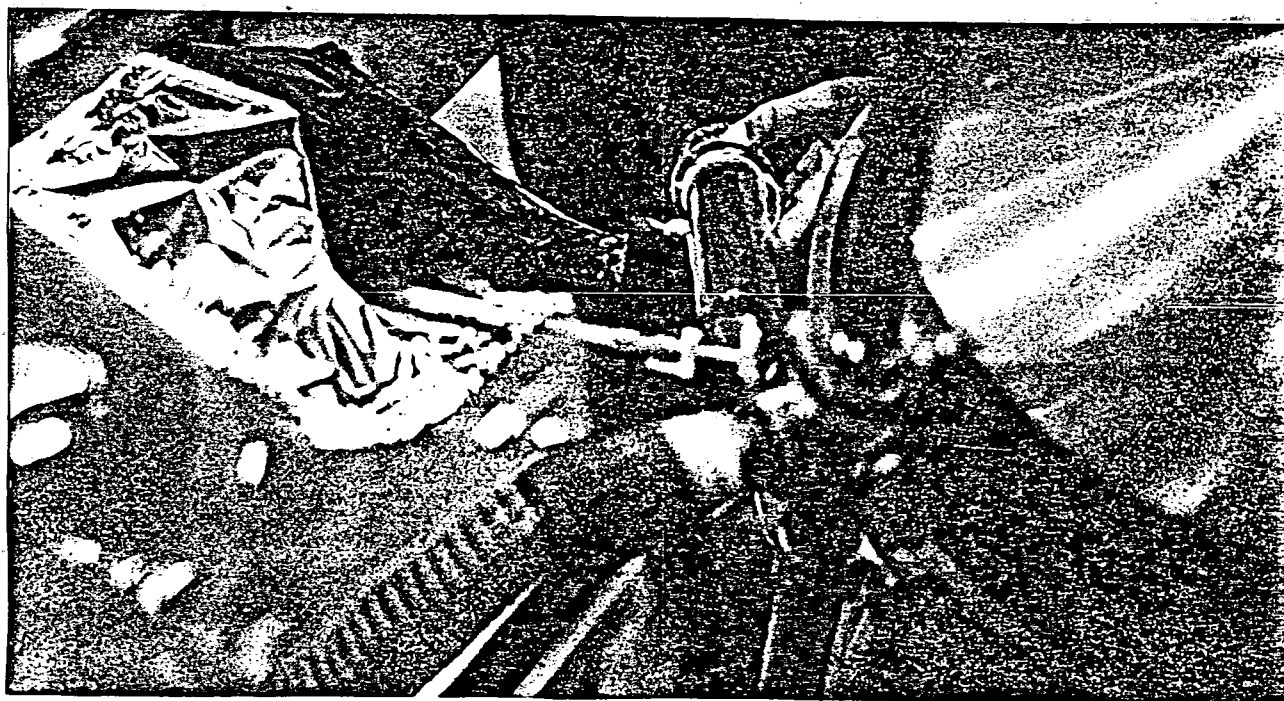
Testing for VO_2 max

Figure 4

Collection of Sample Expired Gas

for O_2 and CO_2 Analysis

The warmup procedure consisted of a 500-yard swim performed by all subjects. Because of the relative ease of the first two work bouts, it was felt that a 500-yard warmup would be adequate. As all work bouts were performed using the front crawl stroke, the warmups, likewise, consisted of the front crawl.

It was during this warmup period that the investigator measured the air and water temperatures, the humidity and the barometric pressure, and recorded these on the subject's data collection sheet. The swimming pool environmental level conditions were maintained at the constant during all testing.

Before the testing began, each subject was fitted with swim goggles, nose clips, the belt of the swimming ergometer, and the mouth piece of the gas collection unit.

Workloads for each work bout were determined by weights added to the swimming ergometer. These were added in increments of one and two pounds. The first and continuing workloads were selected according to the subject's caliber and training ability. All subjects reached $\dot{V}O_2$ max during test (T_1) and retest (T_2).

Each workload was started with the subject in a prone position, as pictured in Figure 3. The subject then swam in place, being held there by the weight attached to the cable. The subject kept his/her head located between the two rubber bricks on the pool bottom. This allowed for a variance of movement of three feet during the work bout. At one minute into each work bout, the lap counter located on the pool bottom was turned to the number one by a lab assistant. At two minutes the lap counter was turned to two. This allowed the subject to know how far into the work bout he/she was. At two minutes and 30 seconds into the work bout, expired air was collected in the Tissot gasometer for 30

seconds. While the expired air was being collected, a 300-milliliter sample was drawn off (see Figure 4) for separate gas analysis. At the end of three minutes, the collection of expired gas was stopped and the subject ceased the work bout. An assistant then immediately palpated the standing subject's carotid artery for a post-exercise heart rate for 10 seconds, while the subject looked at the RPE chart and chose a number corresponding to his/her effort. The subject then rested five minutes, while all equipment was reset and the workload was increased accordingly.

The only adjustment in this schedule was in the final workload. If the subject could not complete the workload after one minute and 30 seconds, then notice was given to the investigator and expired gas was collected the same as in work bouts which were three minutes.

Scoring of Data

Prior to each subject's testing, air and water temperatures, humidity, and barometric pressure were taken and recorded on the Data Collection Sheet. The temperature of the expired gas was also recorded. These measurements were taken to ensure proper environmental levels and correct readings to BTPS.

Skinfold calipers were used to take measurements at the base of the right triceps and right subscapular positions. The measurements were then used to determine the percentage of body fat using nomograms for boys and girls, developed by Parizkova (35).

In the last 30 seconds of each workload, expired gas was collected. The volume was converted to BTPS and the O_2 and CO_2 levels were determined by analysis. With these scores, $\dot{V}O_2$ max was determined in liters per minute (l/min), according to Consolazio et al. (4).

Each subject's weight in kilograms was then combined to determine VO_2 max in milliliters per kilogram per minute (ml/kg/min).

Using Parizkova's (35) nomogram to determine the percentage of body fat, VO_2 max was also determined using the remaining percentage of total body weight, known as the lean body mass. This form of VO_2 max is known as milliliters per kilogram of lean body weight per minute ($\text{ml/kg}\cdot\text{lbw/min}$).

At the completion of each workload, RPE and heart rate were recorded. Ratings of perceived exertion were determined by recording the number which each subject gave to estimate his/her exertion, as indicated on the Borg (3) six to 20 scale. Heart rates were taken for 10 seconds and recorded in beats per minute.

Treatment of Data

An intraclass correlation coefficient (2) was computed to determine the test/retest reliability of the following variables: (1) VO_2 max in l/min , (2) VO_2 max in ml/kg/min , (3) VO_2 max in $\text{ml/kg}\cdot\text{lbw/min}$, (4) VE max, (5) HR max, and (6) O_2 pulse max. The .05 level was selected to test all hypothesis.

Summary

The 20 subjects for this study consisted of nine males and 11 females, ranging in age from 12 to 18 years, and whose abilities ranged from beginning competitive to elite.

A modified version of Costill's swimming ergometer (19) was used to elicit VO_2 max. The expired gas was collected with a Tissot gasometer to measure volume and temperature while a 300-milliliter

sample was rechanneled into sample bags for O_2 and CO_2 gas analysis.

Borg's (3) six to 20 RPE Scale was used to assess ratings of perceived exertion upon completion of each work bout by each subject.

Prior to testing, all anthropometric data were recorded as were environmental conditions.

All swimming work bouts during the two testing sessions took place using the swimming ergometer. A 500-yard warmup, swimming the crawl stroke, was swum prior to each testing session.

Workload increments added to the swimming ergometer were selected according to the subject's caliber and training ability. All subjects reached VO_2 max during test (T_1) and retest (T_2).

Each workload lasted three minutes with expired air collected for the last 30 seconds. At the completion of each workload, the subject's post-exercise heart rate was taken.

VO_2 max was determined in liters per minute, milliliters per kilogram per minute, and milliliters per kilogram of lean body weight per minute. VO_2 max ($ml/kg \cdot lbw/min$) was determined by first using skinfold thickness calipers to determine percentage of body fat according to Parizkova (35) and then converting to lean body weight.

Chapter 4

ANALYSIS OF DATA

The results of this investigation are presented in this chapter. The primary divisions of the chapter include: (1) means and standard deviations for anthropometric measurements, (2) means and standard deviations for test/retest physiological variables, (3) intraclass correlation coefficients for test/retest physiological variables, and (4) summary.

Means and Standard Deviations for Anthropometric Measurements

Table 8 contains the means and standard deviations of the anthropometric measurements collected in the present study. Means and standard deviations were calculated for age, height, weight, body surface area (BSA), percentage of body fat, lean body weight, and fat body weight. The means and standard deviations for weight, BSA, lean weight, and fat weight were calculated for both trial one (T_1) and trial two (T_2).

Means and Standard Deviations for Test/ Retest Physiological Variables

Table 9 contains the means and standard deviations for the test/retest physiological variables. Means and standard deviations were calculated for the following variables: VE max BTPS, VO_2 max in l/min, VO_2 max in ml/kg/min, VO_2 max in ml/kg·lbw/min, heart rate max, and O_2 pulse max. The means and standard deviations of these variables were computed for males (N=9), females (N=11), and males and females (N=20).

Table 8

Anthropometric Characteristics
of Male and Female
Age-Group Swimmers

Variable	Males N=9				Females N=11			
	\bar{X}		SD		\bar{X}		SD	
	T ₁	T ₂	T ₁	T ₂	T ₁	T ₂	T ₁	T ₂
Age	15.1	-	2.04	-	14.6	-	1.49	-
Ht (cm)	172.5	-	12.12	-	167.1	-	5.52	-
Wt (kg)	64.9	64.5	11.80	11.54	58.6	58.0	7.49	7.36
BSA	1.78	1.77	.23	.22	1.66	1.66	.16	.12
% Fat	16.4	-	3.41	-	20.1	-	3.10	-
Lean Wt	54.5	54.1	11.55	11.24	46.6	46.2	4.76	4.57
Fat Wt	10.5	10.4	2.06	2.09	11.9	11.8	3.30	3.23

Table 9

Physiological Characteristics
of Male and Female
Age-Group Swimmers

Variable	Males N=9				Females N=11				Males & Females N=20			
	\bar{X}		SD		\bar{X}		SD		\bar{X}		SD	
	T ₁	T ₂	T ₁	T ₂	T ₁	T ₂	T ₁	T ₂	T ₁	T ₂	T ₁	T ₂
VE max BTPS	92.0	89.4	17.5	18.7	78.8	76.8	16.0	14.5	84.7	82.5	17.6	17.3
V _{O₂} max l/min STPD	3.70	3.59	.87	.87	2.95	2.97	.47	.47	3.28	3.25	.77	.73
V _{O₂} max ml/kg/min	56.7	55.1	6.3	5.5	50.6	51.3	7.4	6.2	53.3	53.0	7.4	6.0
V _{O₂} max ml/kg·lbw/min	67.9	66.0	7.2	5.7	63.2	64.2	7.8	6.8	65.3	65.0	7.7	6.2
Heart Rate max	172.7	171.6	16.6	12.5	162.0	168.0	11.7	12.6	166.8	169.6	14.8	12.3
O ₂ Pulse max	22.0	21.1	6.1	6.0	18.2	17.7	3.0	2.3	19.9	19.2	4.9	4.6

Intraclass Correlation Coefficients for Test/Retest Physiological Variables

The results of the intraclass correlation coefficients for the physiological variables are listed in Table 10. They show high reliability for all variables in a test/retest, except the heart rate maximum. These results are consistent for males, females, and all subjects.

These results lead to the rejection of the three major null hypotheses, these being that there will be no significant correlation between a test/retest of $\dot{V}O_2$ max in (1) l/min, (2) ml/kg/min, and (3) ml/kg·lbw/min in age-group swimmers using a swimming ergometer.

The intraclass correlation for the physiological variable, maximal heart rate in males, females and all subjects led to the acceptance of the minor null hypothesis H_{01} , that being that there will be no significant correlation between a test/retest of maximal heart rate in age-group swimmers using a swimming ergometer.

The high intraclass correlation of the physiological variables maximal ventilation and maximal O_2 pulse led to the rejection of the minor null hypotheses H_{02} that there will be no significant correlation between a test/retest of maximal O_2 pulse in age-group swimmers using a swimming ergometer, and H_{03} , that there will be no significant correlation between a test/retest of maximal ventilation in age-group swimmers using a swimming ergometer.

Summary

Means and standard deviations were computed for the anthropometric variables age, height, weight, body surface area, percentage of

Table 10

Reliability for Physiological Parameters

Variable	R (Intraclass Correlation)		
	Male N=9	Female N=11	All Subjects N=20
VE max BTPS	.93	.96	.95
VO ₂ max STPD l/min	.98	.98	.98
VO ₂ max STPD ml/kg/min	.90	.96	.94
VO ₂ max STPD ml/kg·lbw/min	.88	.95	.91
Heart Rate max	.38	.45	.45
O ₂ Pulse max	.95	.88	.95

body fat, lean body weight, and fat body weight. These means and standard deviations are listed in Table 8.

Table 9 contains the means and standard deviations for the test/retest physiological variables VE max, VO_2 max (l/min), VO_2 max (ml/kg/min), VO_2 max (ml/kg·lbw/min), heart rate max, and O_2 pulse max.

The results of the intraclass correlation coefficient for the physiological variables listed in Table 10 show high reliability in a test/retest for all variables except maximal heart rate. These results led to the rejection of the three major null hypotheses, the acceptance of minor null hypothesis H_{0_1} , and the rejection of the minor null hypotheses H_{0_2} and H_{0_3} .

Chapter 5

DISCUSSION OF RESULTS

The emphasis of this chapter is a discussion and interpretation of the results reported in Chapter 4. The topics included are the reliabilities of the physiological variables in a test/retest of age-group swimmers for $\dot{V}O_2$ max using a swimming ergometer. These variables include: (1) $\dot{V}O_2$ max in l/min, (2) $\dot{V}O_2$ max in ml/kg/min, (3) $\dot{V}O_2$ max in ml/kg·lbw/min, (4) maximal ventilation, (5) maximal O_2 pulse, and (6) maximal heart rate.

In exercise of moderate duration, the realm of oxygen transport performance may be influenced by non-physiological variables. These include efficiency of effort, motivation, and strength of individual muscle groups. However, at $\dot{V}O_2$ max, studies (17, 21, 23, 24, 27, 30, 31) have shown that, with specific ergometry, these variables are not a factor in oxygen transport performance. $\dot{V}O_2$ max plays the primary role in oxygen transport performance. As such, the ability to reliably test for $\dot{V}O_2$ max of age-group swimmers using a swimming ergometer is very important.

The reliability of the swimming ergometer to determine $\dot{V}O_2$ max was very high in the three forms tested (l/min, ml/kg/min, and ml/kg·lbw/min). The reliability of $\dot{V}O_2$ max STPD in l/min for this study was .98 for males, females, and all subjects. This corresponds favorably to a study done by Magel and Faulkner (28), who reported a reliability of .93 in a test/retest of 26 highly trained male college swimmers for

VO_2 max STPD l/min using a swimming ergometer. Costill (11), in a test/retest of 13 male college swimmers, also revealed a high reliability of .91 for VO_2 max STPD l/min using a swimming ergometer. This study was the first to test for the reliability of VO_2 max using a swimming ergometer with age-group swimmers. This study shows that reliabilities are high for both college swimmers and age-group swimmers using the swimming ergometer. The VO_2 max l/min of this study's subjects, compares well with the related literature. Cunningham and Eynon (15) reported a VO_2 max l/min of 2.11 for age-group girls and 2.94 for age-group boys that were training in swimming. This present study reports VO_2 max l/min of 2.96 for girls and 3.60 for boys. Holmer et al. (23), for elite swimmers, reported scores of 3.42 for 11 girls with a mean age of 17, and 5.05 for 12 men with a mean age of 19.

The present study also demonstrated a high reliability of VO_2 max STPD in ml/kg/min. The reliability was .90 for males, .96 for females, and .94 for all subjects. Again, these correlations correspond favorably to those reported by Magel and Faulkner (28), whose data revealed a reliability coefficient factor of .83 for 26 highly trained college swimmers.

The third method used to measure VO_2 max STPD was in ml/kg·lbw/min. The reliabilities were .88 for males, .95 for females, and .91 for all subjects. Though the reliabilities of VO_2 max STPD in ml/kg/min and ml/kg·lbw/min were high, their use to express VO_2 max STPD in swimmers has been questioned. Holmer et al. (23) suggested that VO_2 max STPD in swimming should not be expressed in ml/kg/min, since less work is needed to support the body weight in water as opposed to treadmill or bicycle ergometry. However, this author claims that, in

testing for the reliability of $\dot{V}O_2$ max STPD using a swimming ergometer, the inclusion of body weight (ml/kg/min) and lean body weight (ml/kg·lbw/min) are important when dealing with age-group swimmers. This method of determining physiological fitness is important as the lean body weight is continuously changing during the swimmer's growth. Therefore, in charting the physiological growth of swimmers, it is important to have a reliable method of testing their $\dot{V}O_2$ max STPD in terms of body weight and lean body weight. Though body weight is supported in swimming, the buoyancy provided according to the percentage of body fat and the effects of body fat and body weight on hydrodynamics are important considerations in future physiological-hydrodynamic studies in swimming. Astrand et al. (8) pointed out that girls have far greater chances of being prominent at an early age in sport events that make large demands on oxygen transporting organs. This is due to a low percentage of body fat. As girls reach puberty, body fat percentages increase up to 50 percent. $\dot{V}O_2$ max ml/kg·lbw/min then becomes important to the swimming coach when coaching girls with a high percent of body fat and events that make large demands on oxygen transporting organs.

In examining the $\dot{V}E$ max BTPS for reliability, it was found to be highly reliable through test/retest. The males showed a reliability factor of .93, the females .96, and all subjects .95. Though $\dot{V}E$ max BTPS has been found to be lower in swimming than in bicycling or running (17, 21, 23, 24, 27, 30, 31), its reproducibility on the swimming ergometer in the present study was reliable.

The O_2 pulse variable also showed a high reliability during test/retest. The male reliability coefficient was .95 for males, .88 for females, and for all subjects .95. O_2 pulse, being a relative

measure of stroke volume, plays a significant role in VO_2 max testing. Astrand et al. (8) reported a high correlation between VO_2 max and heart volume of .90 and suggested that, in healthy persons, the heart volume represents its stroke volume.

The low-reliability of the heart rate max in test/retest led to the acceptance of the minor null hypothesis H_{01} , that being that there will be no significant correlation between a test/retest of maximal heart rate in age-group swimmers using a swimming ergometer. The reliabilities were .38 for males, .45 for females, and .45 for all subjects. Costill (11), using 13 male college swimmers, reported a reliability of .86 for heart rate max. However, an electrocardiograph was used to record heart rates. Magel and Faulkner (28), in a test/retest of 17 college swimmers, showed a reliability of .76 for heart rate max. In the present study, the subjects' heart rates were determined from a pulse count taken at the carotid artery from 5 to 20 seconds after the swim. It is possible that this measurement technique imposed a serious limitation on the assessment and the interpretation of heart rate data. In the present study, there may have possibly been an error in palpation of three subjects whose heart rates max varied by 30 beats from test to retest, the next highest variances being 18.

In the present study, the post-exercise heart rates were determined by palpation of the carotid artery for 10 seconds immediately after the work bouts were finished. This investigator suggests that the use of an electrocardiograph instead of post-exercise palpation might have produced higher reliabilities and would be much better than the extrapolation method. Davies (16) pointed out that the major drawback to all extrapolation methods is the asymptotic nature of the

heart rate/ $\dot{V}O_2$ curve. In other words, the heart rate reaches maximum before $\dot{V}O_2$ does. Davies (16:700) also reported that "... heart rate undergoes random day-to-day variations quite independently of $\dot{V}O_2$ and is affected by temperature and training." All these factors could give rise to serious error and impair the accuracy of extrapolation procedures in the individual case.

Chapter 6

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The purpose of this study was to test the reliability of the swimming ergometer in obtaining $\dot{V}O_2$ max of male and female age-group swimmers.

The subjects (N=20) consisted of 9 males and 11 females who ranged in age from 12 to 18 years and whose abilities as swimmers ranged from beginning competitive to elite.

All swimming work bouts took place using the swimming ergometer. The data were collected during two testing sessions. The data consisted of physiological, anthropometric, and training characteristics.

The warmup procedure consisted of a 500-yard swim performed by all subjects. Progressive workloads were used according to the subjects' caliber and training ability. All subjects reached $\dot{V}O_2$ max during test and retest. At two minutes and 30 seconds into each progressive work bout, expired air was collected for 30 seconds and analyzed. At the conclusion of each workload, ratings of perceived exertion and heart rates were obtained.

$\dot{V}O_2$ max was determined in liters per minute, milliliters per kilogram per minute, and milliliters per kilogram of lean body weight per minute.

The results of the intraclass correlation coefficient showed very high reliabilities for VE max .95, $\dot{V}O_2$ max l/min .98, $\dot{V}O_2$ max ml/kg/min .94, $\dot{V}O_2$ max ml/kg·lbw/min .91, and \dot{O}_2 pulse .95. The heart rate

max was unreliable with a .45 coefficient. It was felt that this was due to a human error in the carotid palpation.

Conclusions

Within the limitations of the study, the following conclusions were drawn:

1. The swimming ergometer used in the present study is a reliable method of obtaining $\dot{V}O_2$ max in age-group swimmers.
2. $\dot{V}O_2$ max recorded using the swimming ergometer is reliable in terms of l/min, l/kg/min, and l/kg·lbw/min. The reliability for VE max and O_2 pulse max are high in age-group swimmers using a swimming ergometer.
4. Heart rate max, though a predictor of $\dot{V}O_2$ max, was not reliable enough to predict $\dot{V}O_2$ max in this study.

Recommendations

Upon completion of this investigation, the author suggests the following recommendations for further study:

1. A study to correlate $\dot{V}O_2$ max training levels and performance of age-group swimmers in events that demand high levels of $\dot{V}O_2$.
2. A study to compare the $\dot{V}O_2$ max of swimmers using all four competitive strokes.
3. A study to compare the quantity and quality of swim training to increases in $\dot{V}O_2$ max of swimmers.
4. A study to compare the effects of post-pubescence body gains on $\dot{V}O_2$ max ml/kg/min and ml/kg·lbw/min in highly trained female swimmers.
5. A study to determine the reliability of using the rate of perceived exertion scale to predict the $\dot{V}O_2$ max of swimmers using a swimming ergometer.

APPENDICES

Appendix A

THE SIX TO TWENTY RPE SCALE

PERCEIVED EXERTION

- 6
- 7 Very, very light
- 8
- 9 Very light
- 10
- 11 Fairly light
- 12
- 13 Somewhat hard
- 14
- 15 Hard
- 16
- 17 Very hard
- 18
- 19 Very, very hard
- 20

Appendix B

DATA COLLECTION SHEET

Subject: _____ Best Times _____ Body Fat % : :
Height : _____ T₁ T₂ Triceps : :
Weight : _____ Age : _____ Years swimming _____
Subscapular : :

Test #1 _____ Weight _____ Gas-H₂O-Air _____ Barom.Press. _____ Time _____ Tissot Gas Vol. _____ O₂% _____ CO₂% _____ True O₂ _____ H.R. _____ P.E. _____
1) _____
2) _____
3) _____
4) _____
5) _____

Test #2 _____
1) _____
2) _____
3) _____
4) _____
5) _____

Appendix C

INSTRUCTIONS OF WORK BOUTS ON THE SWIMMING ERGOMETER

You are now looking at a swimming ergometer. Except for a belt at your hips, it is a free swimming device (Figure 1). You will put on the belt, with the adjustable cable loops opposing each other. Five successively harder work bouts will be performed, each of three minutes duration. You will keep your head located between the two rubber bricks on the pool bottom (Figure 2). This will allow a range of forward horizontal motion of three feet. You must stay between these bricks during each work bout. A lap counter situated one foot past the second brick will be used to tell you when you have finished the first and second minutes of each work bout. Should you not be able to finish a work bout, give the investigator 30 seconds to obtain an air sample. This will be done by your recovering with your left arm straight for one stroke, then continuing the work bout for 30 more seconds. Upon a signal given at the end of three minutes, you will stop and stand up and immediately look at the RPE chart and give the investigator a number. There will be a five-minute rest between each work bout.

Appendix D

INSTRUCTIONS: RATINGS OF PERCEIVED EXERTION

You are now looking at a scale containing the numbers from 6 to 20. This scale is used so that you can translate your feelings into numbers. The range of numbers represents a range of feelings from "No exertion at all" (number 6) to "Maximal exertion" (number 20). Every other number has a verbal expression attached to help you select a number that corresponds to your subjective feelings. Your goal is to rate your feelings which are a result of the work and not the work itself. These feelings should be general, that is, about the body as a whole. You are asked not to specify the feeling, but to select a number which most accurately corresponds to your perception of your total body feeling. Remember that there are no right or wrong numbers, use any number you think appropriate.

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