THE EFFECTS OF TWO BREATHING PATTERNS ON SELECTED PHYSIOLOGICAL PARAMETERS DURING A SIMULATED 200 YARD FREESTYLE IN MALE SWIMMERS

by

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CHAPTER 1

INTRODUCTION

The primary distance of men's varsity collegiate swimming events is 200 yards, yet swimmers are often called upon to compete in events which range from 50-1000 yards in length. Of importance to coaches and researchers is the duration of these events, since duration is an indicator of whether aerobic or anaerobic energy sources are utilized (Counsilman, 1975). Under maximal effort conditions, events up to 100 yards in length are considered anaerobic and are dependent upon high energy phosphates as the predominant source of energy. Events which are considered aerobic, i.e., those over 300 yards in length, utilize oxygen for the combustion of carbohydrates and fats into energy (Counsilman, 1975; Kedrowski, 1976). The 200-yard event, which is considered middle-distance, has been thought to rely equally on both of these energy systems (Kedrowski, 1976), although Counsilman (1975) suggested that the anaerobic system was the dominant source of energy. Specific to this study was the 200-yard freestyle event, performances for which range between 108-114 sec for successful male collegiate swimmers.

Based on metabolic demands and the rate of energy expenditure during swimming, leading swim coaches have prescribed various training methods with the intend of producing physiological changes which may enhance 200-yard swim performance. One method which has recently gained wide visibility is referred to by coaches as hypoxic breathing. Hypoxic conditions exist when a diminished supply of oxygen is offered to the tissues per liter of arterial blood (Astrand & Rodahl, 1970), and during swimming this is presumed to occur as a result of reduced ventilation. It remains to be demonstrated experimentally, however, that an exaggerated tissue hypoxia results from this voluntary reduced breathing frequency or whether compensatory increases in the regional blood flow to active areas may actually act to maintain tissue oxygenation despite the relative reduction in ventilation. Counsilman (1975) and Kedrowski (1976) both suggested that under hypoxic conditions oxygen supply is reduced in the tissues; in support of this notion, Counsilman (1975) observed greater oxygen debt and higher blood and muscle lactic acid concentrations in swimmers using hypoxic breathing during submaximal swimming when compared to breathing freely under similar swimming conditions. Haines (1975) suggested that if a swimmer can become accustomed to working under hypoxic conditions the physiological changes will increase performance. He further suggested that reduced breathing will enhance performance by enforcing a more biomechanically efficient body position, in that with a reduced frequency of rotation of the head to breathe, there will be less resistance and fewer hesitations in the stroke than if breathing were synchronized with each stroke. The most popular hypoxic training technique is a two-stroke breathing pattern (Schubert, 1976), and its use has been prescribed for up to half the total workout (Kedrowski, 1976). To date, the physiological-biomechanical consequences of hypoxic breathing remain obscure.

Justification of the Study

Due to the prevalence of the 200-yard/200-meter event in collegiate and Olympic swimming, it is important to investigate the physiological demands encountered during an event of this duration. Also of interest is the use of hypoxic breathing which was popularized by the published opinion of leading practitioners (Counsilman, 1975; Haines, 1975; Kedrowski, 1976; Schubert, 1976).

Several benefits of hypoxic breathing have been postulated in the literature by leading coaches. Biomechanically, the body is more streamlined when breathing is less frequent due to the stabilization of the head, thorax, and abdomen, which reduces rotation in the head and shoulders (Kedrowski, 1976; Neeves & Brown, 1975; Schubert, 1976). Other findings (Kedrowski, 1976) indicated that, during breathing, the swimmer shortens his pull resulting in hesitation in the arm stroke and a premature release of the water. Kedrowski further suggested that there are physiological adaptations to reduced oxygen and high lactate concentrations which he considered the main limitations in a 200-yard swim. Despite the lack of research in these areas coaches are now recommending the use of hypoxic breathing not only for the purpose of training, but during competition (Haines, 1975). Nevertheless, no biomechanical or physiological evidence could be found to substantiate these claims, and only one study (Hermansen, 1969) was found on the anaerobic energy demands of swimmers during a 200-meter freestyle swim.

Statement of the Problem

The purpose of this study was to determine the effects of two breathing patterns on selected physiological parameters during a simulated 200-yard freestyle swim in competitive male adolescent and young adult swimmers. Specifically, a comparison of oxygen uptake, blood lactic acid, ventilation, and the respiratory exchange ratio responses to a timed swim were made under the following experimental conditions: Condition 1, associated with relative tachypnea, wherein the subject was required to breathe every arm stroke; and Condition 2, associated with relative hypopnea, wherein the subject was required to breathe only on alternate arm strokes, or half as frequently.

Null Hypotheses

The following null hypotheses were tested:

1. No significant differences would be observed between oxygen uptake values under the two experimental conditions.
2. No significant differences would be observed between blood lactic acid concentrations under the two experimental conditions.
3. No significant differences would be observed between the respiratory exchange ratios under the two experimental conditions.
4. No significant differences would be observed between ventilation values under the two experimental conditions.

Delimitations

The following delimitations were imposed:

1. The sample size was limited to 10 male subjects.
2. Selection of participants was restricted to males aged 15-22 years.
3. Investigation of performance was restricted to the crawl

stroke.

4. Swim time during the experimental trials was 110 sec.

5. Work intensity during the experimental trials was 95% of weight displaced during maximal tethered swimming test.

Limitations

Certain limitations were present in the study. During tethered swimming a headpiece was worn, and the subject was required to maintain visual contact with a diving brick placed on the bottom of the pool. Under these conditions the head position was lowered causing less rotation in the shoulders. Nevertheless, there was total freedom of movement, and propulsive mechanics were not altered.

Assumptions

The following assumptions were evident in this study:

1. All swimmers were equally capable of breathing under the conditions specified in the study.

2. The tethered swimming apparatus simulates the physiological-biomechanical demands encountered during a 200-yard swim.

3. All subjects performed until exhaustion.

Definitions

1. $\dot{V}O_2$ max. The peak rate of oxygen consumption for a subject during maximal intensity exercise involving the large muscles of the body. The $\dot{V}O_2$ max calculated in $ml/kg \cdot min^{-1}$ expresses the capacity of the individual per unit of body mass (Astrand & Rodahl, 1970).

2. Arm Stroke. A complete left and right arm pull in the swim cycle (Schubert, 1976).

3. Hypoxic Breathing. A voluntary reduction in respiratory frequency which is purported to diminish the supply of oxygen to the tissues per liter of arterial blood (Astrand & Rodahl, 1970).

4. Aerobic Exercise. Exercise under conditions wherein the oxygen supply to the muscles is equal to the oxygen demand. During aerobic exercise pyruvate is oxidized in the Krebs cycle, with the release of carbon dioxide, water, and energy (Edington & Edgerton, 1977).

5. Anaerobic Exercise. Exercise of short intense duration wherein the oxygen demand exceeds the oxygen supply, resulting in the accumulation of lactic acid. During anaerobic exercise, the predominant metabolic pathway for energy production is glycolytic (Edington & Edgerton, 1977).

6. Lactic Acid. The by-product of anaerobic metabolism which diffuses from active tissues into blood. Typical blood lactic acid values during a resting stage range from 3-12 mg/dl^{-1} of mixed venous blood (Sigma, 1976), while values obtained just after heavy exercise may exceed 100 mg/dl^{-1} (Hermansen, 1969).

7. Relative Hypopnea. Abnormal decrease in depth and rate of respiration (Dorland, 1968).

8. Relative Tachypnea. Increased frequency of breathing (Comroe, 1965).

CHAPTER 2

REVIEW OF LITERATURE

Recent literature on the physiological parameters of swimmers indicated a specific cardiovascular adaptation to swim training (Dixon & Faulkner, 1971, Magel, Foglia, McArdle, Gutin, Pechar, & Katch, 1974; Stromme, Inger, & Meen, 1977). Cooper (1967) found lower vital capacities and bradycardia in individuals submerged to neck level in water due to increased pressure on the thoracic cavity, although other investigators (Ekblom, Astrand, Saltin, Strenberg, & Wallstrom, 1968; Falls, 1968; Nomura & Reddan, 1974; Sprague, 1976) found a reduced vital capacity in subjects exercising in a recumbent position. In addition, researchers have found water to directly affect heat transfer (Costill, 1968; McArdle & Magel, 1976), so that upon immersion into water the flow of blood into the skin for cooling was reduced, thus enabling more oxygenated blood to circulate in the muscles.

Due to these specific physiological effects of water immersion and exercise in the water, it is important to assess the physiological parameters of swimmers under conditions wherein the swimmer is performing in the water. This chapter, therefore, includes a review of literature on the specific nature of (1) aerobic assessment of swimmers; (2) anaerobic assessment of swimmers; (3) respiratory-pulmonary responses to stressful swimming; and an additional section, (4) the validity and reliability of capillary blood lactic acid determination, to review the literature on micro-determination procedures of capillary blood lactic acid.

Aerobic Assessment of Swimmers

The cardiorespiratory capacity of swimmers has been measured during running (Dixon & Faulkner, 1971; Magel & Faulkner, 1967; Magel, et al., 1974), bicycling (Cunningham & Enyon, 1973; Secher & Oddershede, 1974), free swimming (Magel & Faulkner, 1967; McArdle, Glasser & Magel, 1971), tethered swimming (Magel & Faulkner, 1967; Magel, et al., 1974; Neeves & Brown, 1975), and in the flume (Holmer, 1972). Although free, tethered and flume swimming are biomechanically and physiologically specific to swimming, differences were found to exist between these and other methods of oxygen uptake assessment (Dixon & Faulkner, 1971; Magel & Faulkner, 1967). Similar oxygen uptake capacities were reported between tethered swimming and treadmill running (Dixon & Faulkner, 1971; Magel & Faulkner, 1967), while other investigators reported significant differences between free swimming and tethered swimming (Magel & Faulkner, 1967), between cycling and running (Astrand & Saltin, 1961), and treadmill running and tethered swimming (Magel, et al., 1974). It has been stated that the observed differences in aerobic capacities during swimming, when that finding was reported, were perhaps due to the simulation of swimming under tethered conditions, as opposed to free swimming. Nevertheless, Goff, Brubach, and Specht (1957) studied swimmers underwater and found differences in body attitude and in the hydrodynamics of tethered swimming and free swimming and concluded that a direct comparison between the two forms of exercise was extremely difficult.

Magel and Faulkner (1967) analyzed the differences in oxygen uptakes of college swimmers during treadmill running, tethered swimming, and free swimming. They found a moderately high positive correlation ($\underline{r}$=.85) between the level of oxygen uptake capacity obtained during treadmill running and that for tethered swimming. Additionally, they concluded that maximal oxygen uptakes obtained during free swimming were significantly higher than during tethered swimming, possibly due to a training effect. Nevertheless, they found no statistically significant differences with respect to oxygen extraction, pulmonary ventilation, and respiratory rate during tethered swimming and those obtained during free swimming. Holmer (1974) questioned Magel and Faulkner's findings in view of the observation that their $\dot{V}O_2$ max data measured under tethered conditions were obtained at a point later in the training season.

Dixon and Faulkner (1971) tested six college trained swimmers during both maximal efforts in treadmill running and in tethered swimming, and compared them with recreational swimmers for cardiac output. They found that cardiac output and maximal oxygen uptake were not significantly different in swimming and running.

Magel, et al., (1974), in a more definitive and recent study, used 30 college-age recreational swimmers to assess aerobic capacities during treadmill running and tethered swimming. They found a significant difference in aerobic capacities obtained between running and swimming after a period of swim training, and concluded that there was a specific cardiorespiratory adaptation to swim training in male recreational swimmers.

Anaerobic Assessment of Swimmers

Few studies have analyzed the physiological parameters of swimmers during anaerobic exercise. Perhaps the most definitive research conducted on the anaerobic assessment of swimmers was by Secher and Oddershade (1975). Their subjects consisted of 5 trained and 5 recreational swimmers who were chosen so that inter-individual differences with regard to swimming experience could be represented. The subjects performed six to seven 30 sec swims at maximal speed interspersed with 10 sec rest intervals in a swimming flume and on a bicycle ergometer. The findings showed that 4 of the 5 swimmers had higher $\dot{V}O_2$ max for bicycling than for a comparable effort in the flume. They found their results concurred favorably with Magel and Faulkner (1967) in that the best swimmers had $\dot{V}O_2$ max values of less than 4 l/min^{-1}, and that oxygen consumption in swimming was approximately 15% above running $\dot{V}O_2$ max.

Hermansen (1969) tested two national caliber swimmers to determine the oxygen debt during 100-meter and 200-meter freestyle swims. He found oxygen debt to increase as swim speed increased during both 100-meter and 200-meter swims. In addition, he found blood lactate concentrations to increase throughout a 7 month period of swim training based on the results of periodic 100-meter swim tests. A rapid decrease was observed during a 2-month period of no training. Lactic acid values, obtained from a venous sample, for the trained swimmers ranged from 130 mg/dl^{-1} of blood at the onset of training to over 160 mg/dl^{-1} of blood at the termination.

Knowlton, Sawka, Miles and Critz (1978) measured blood lactate concentrations after 100- and 200-yard competitive and non-competitive swims. Blood samples were taken 5 min after the completion of each swimmer's event, and lactate was analyzed using an enzymatic method. Blood lactate levels ranged between 148 and 185 mg/dl^{-1} of blood after the 200-yard competitive swimming event. They concluded that competitive swimming requires a large participation from anaerobic metabolism.

Respiratory and Pulmonary Responses to Stressful Swimming

To date, little research has been conducted on the respiratory and pulmonary responses to stressful swimming. It has been shown (Ekblom, 1970) that upon immersion into water the combination of body density, functional residual capacity, and tidal volume provide a certain degree of buoyancy. Ekblom found buoyancy to be directly proportional to both tidal volume and residual capacity, and inversely proportional to body density.

Astrand (1952) found that when in a recumbent position total lung capacity and vital capacity were reduced 5-10% due to a shift of blood to the thoracic cavity from the lower extremities, reducing venous pooling in the legs and increasing central circulation. In another study on 30 elite female swimmers (Astrand, 1963), he found pulmonary ventilation to be 27.5 liters per liter of oxygen uptake during flume swimming. When compared to cycling, pulmonary ventilation was 35.5 liters per liter of oxygen uptake. He concluded that the 8% lower maximal oxygen uptake observed during swimming as compared to cycling was perhaps due to a reduction of the oxygen tension, thereby reducing oxygen saturation.

Ghesquiere (1975) studied lung volumes during swimming. Although he considered buoyancy to play a relatively minor role in competitive swimming, he identified two factors which affect pulmonary and respiratory function. First, body attitude must be on or near the surface of the water. Secondly, the airways are open only a fraction of the total time during which muscular exertion is performed. The resultant effect of these two factors on pulmonary function is that time for inhalation, which must be above the surface of the water, is short resulting in a diminished PO_2 and an augmented PCO_2 since expiration is performed against the resistance of the water.

The Validity and Reliability of Capillary Blood Lactic Acid Determination

Lactic acid production has been found to be closely related to the intensity of short exhaustive exercise (Astrand & Saltin, 1961; Gollnick, Armstrong, Saltin, Saubert, Sembrowich, & Shepherd, 1973; Hermansen, 1969; Hermansen & Stensvold, 1974; Jorfeldt, 1970; Karlsson, 1971; Karlsson & Saltin, 1971), and as a result, blood lactic acid has been used widely as an indicator of anaerobic metabolism. Consequently, attempts have been made to establish simplified procedures for lactic acid determination (Lundholm, Mohme-Lundholm, & Svedmyr, 1963; Stromme, Inger, & Meen, 1977). Researchers have found methods of utilizing volumes of .1-1.0 ml of blood, yet recent research (Harrower & Brown, 1972) has illustrated the use of volumes of 25-50 µl of blood. This study followed procedures outlined by the Sigma Chemical Company (1976) for the use of 100 µl blood samples.

Concern has developed over the resemblance between capillary blood lactic acid and muscle lactic acid. Karlsson and Saltin (1971) found that during short exhaustive bicycle work, a high muscle lactic acid concentration was closely related to the onset of exhaustion. In an effort to determine the resemblance, Karlsson (1971) tested 28 military inductees, 13 trained and 15 untrained, during short exhaustive bicycle work. He found that immediately after exercise muscle lactic acid averaged 190 mg/dl^{-1} of blood, while capillary blood averaged 112.5 mg/dl^{-1} of blood. After 10 min into recovery values were 90 mg/dl^{-1} and 126 mg/dl^{-1} of blood, respectively, and after 30 min muscle and blood lactate levels were equal. He concluded that the highest blood lactate concentration reflected muscle lactate concentration fairly well after brief, single, exhaustive work at 90-100% of $\dot{V}O_2$ max. In an earlier study (Karlsson, 1970), he reported similar rises in lactate concentration of both blood and muscle lactate during submaximal work lasting 15 min or more on a bicycle ergometer.

A similar study was conducted by Diament, Karlsson, and Saltin (1968). They tested four physical education students on the bicycle ergometer. Data from muscle biopsies taken immediately after 3 min of exhaustive exercise revealed that muscle tissue and blood lactate values were markedly different. Muscle lactate averaged over 200 mg/dl^{-1}, while capillary samples averaged 112.5 mg/dl^{-1}.

Their findings concur with Karlsson's in that lactic acid samples were similar after a 10 min recovery period.

In view of the results by Karlsson (1970), Lundholm, Mohme-Lundholm, and Svedmyr (1965) suggest that the finger tip method of blood sampling is the most practical, since other methods require training. Harrower and Brown (1972), however, cautioned that this method was extremely prone to contamination from the environment and from tissue fluid being squeezed into the blood sample. Nevertheless, Knuttgen (1962) found that by grasping the finger at its proximal end and squeezing out distally, arterial blood could be collected in an average time of less than 9 sec, and therefore be relatively free from further lactate metabolism and skin contact contamination.

Research on the metabolism of lactic acid after exercise is unclear. Several investigations have indicated that post-exercise lactic acid levels increase for 4-5 min into recovery (Hermansen & Stensvold, 1972; Knuttgen, 1962; Margaria, Cerretalli, DiPrampero, Massari, & Torelli, 1963; Prampero, Peeters, & Margaria, 1973), although in one study, it was found lactate increased until 10 min into recovery (Diament, et al., 1968).

Summary

The literature pointed to the importance of assessment of maximal oxygen uptake of swimmers utilizing an apparatus to assess not only the specific physiological changes encountered upon water immersion and lying in a recumbent position, but also the special localized changes brought about by swim training. Of the apparatus mentioned, to account for these variables (i.e., the tethered swimming device, the free swimming technique, and the flume), it was apparent that tethered and free swimming could be expected to yield similar results and were the preferred apparatus in terms and practicality.

Blood lactic acid levels were found to be closely related to muscle lactic acid levels, and therefore a viable method of determining anaerobic metabolism. Efficient methods of blood lactic acid determination were found using capillary blood samples requiring as little as 25 µl of blood.

Lastly, it has been found that a period of 4-5 min into the recovery period after exercise was needed to allow lactic acid levels to peak in the blood.

CHAPTER 3

METHODOLOGY

The methods and techniques utilized throughout this investigation are presented in eight sections. The first section deals with a pilot investigation concerning the validity of capillary blood samples for the use of blood lactic acid determination. The second section identifies subjects used in this study, including a presentation of data for anthropometric and physiologic classification. Section three describes the main apparatus used to obtain all physiological data. The fourth section describes the purpose and method of the Preliminary Test. The fifth section provides the description of and criterion for acceptance of the dependent variables observed in the Preliminary Test, and illustrates their use in the experimental phase of the study. Section six explains the methodology for the Experimental Tests, wherein the two breathing patterns were utilized. Section seven outlines the measurement techniques used in the Preliminary Test and experimental trials, while section eight presents the data analysis procedure.

Validation of Capillary Blood Lactic Acid Procedure

Prior to the experimental phase of the study, a pilot investigation was conducted to determine the validity of capillary blood samples for use in the determination of blood lactic acid. Nine physically active college age men and women not participating in the experimental phase of the study were recruited for this procedure. Each subject swam a maximal effort 200-yard freestyle sprint, after which one of their hands was soaked in hot water for a period while they rested in a seated position near the pool deck. At 230 sec, when lactic acid has peaked (Knuttgen, 1962), simultaneous blood samples were drawn by a registered nurse using a syringe and 22 gauge needle at the antecubital vein, and by the investigator using a lance at the finger tip. Blood specimens from both sites were then collected in identical 100 μl glass Corning Disposible Microliter Pipets and later analyzed for lactic acid content. Values obtained for the two methods are presented in Table 1 and Appendix A.

The mean venous value was found to be higher than the mean capillary value, however, the individual data in Appendix A indicates that only 5 of 9 venous values were higher than their respective capillary samples. In addition, the mean venous values had a lower standard deviation indicating that capillary samples have a greater degree of variation for both low and high values.

In Figure 1, a simple linear regression equation to describe the association of the two lactate distributions is presented. It is apparent that a linear relationship exists between the two samples ($\underline{r}$= .93). The coefficient of determination was calculated to be .86 which indicates a high degree of reproducibility. It was concluded that capillary samples as collected in the pilot investigation are valid for the use of microdetermination of blood lactic acid.

Subjects

The subjects used in the experimental phase of this investigation were 10 male competitive swimmers from Virginia Polytechnic Institute and State University and surrounding communities. They ranged in age from 15-22 years. Each was required to meet the following criteria to

TABLE 1

Comparison of Post-Exercise Lactic Acid Values Collected Simultaneously from Capillary and Venous Blood Samples

	Capillary Value mg/dl^{-1}	Venous Value mg/dl^{-1}
Mean Value	98.4	100.7
SD	37.1	28.7
Range	48-180	60-164
N	9	9

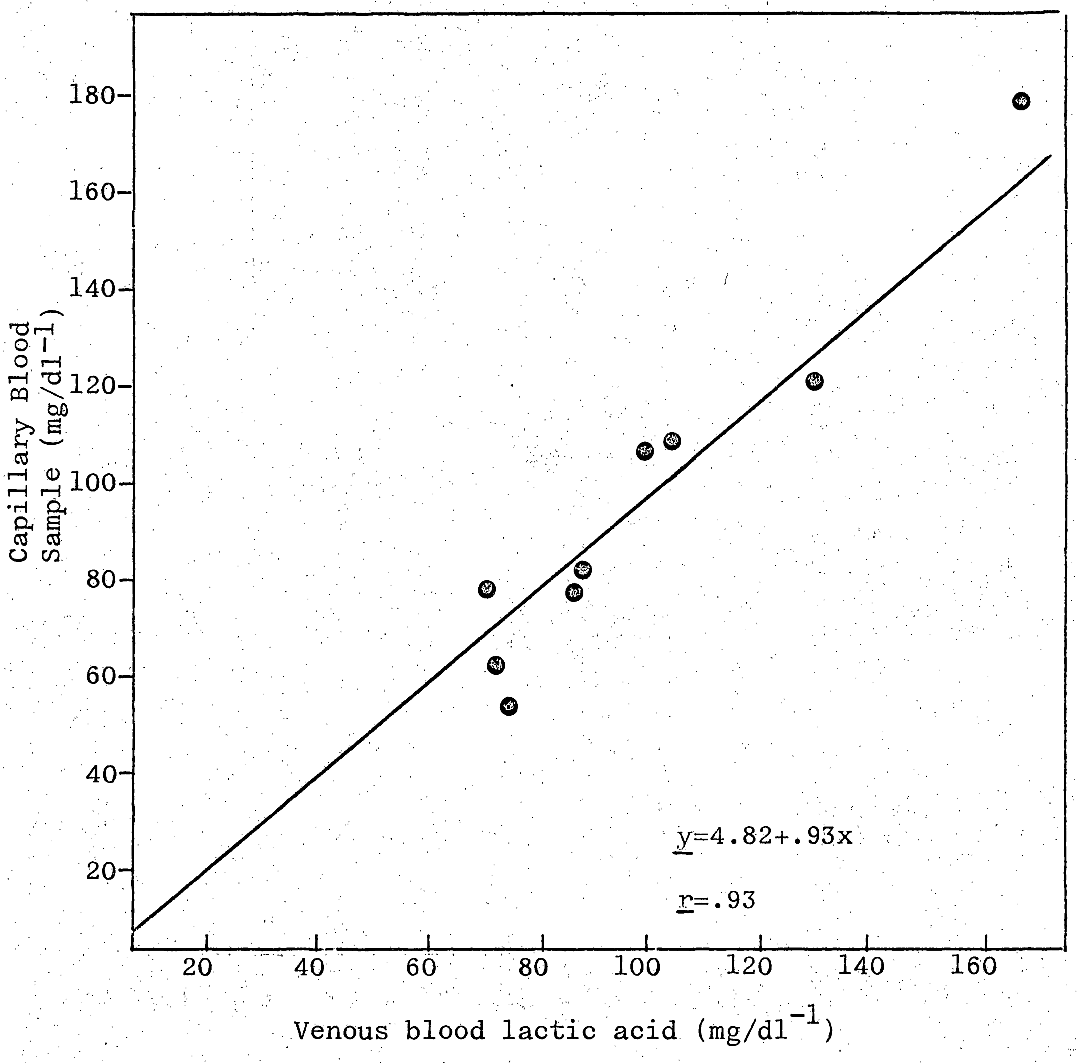

Figure 1. Regression of Capillary and Venous Blood Samples.

qualify for participation in this study;

1. trained competitively for more than 3 years,

2. trained more than 20,000 yards per week for the 6 month period preceding this investigation,

3. swum a timed 200-yard competitive freestyle swim in 114 sec or less within 2 months of the investigation, and

4. trained with no requirements made on breathing pattern.

(However, the preferred breathing pattern of each swimmer in item 4 was to have been only to the left or only to the right.)

All subjects were required to sign an informed consent form prior to the test which contained information as to the nature of the test, variables to be measured, risks to the subject, and benefits expected. Both verbal and written consent were obtained, and subjects were free to withdraw from participation at any time (see Appendixes B and C).

Table 2 and Appendix D contain data on the subjects' characteristics. The mean age of the subjects was 19.3 years, their mean height, weight, and best performance times were 176.3 cm, 77.9 kg, and 111.9 sec, respectively. As can be seen in Appendix E, the subjects in this study were similar to competitive swimmers used in comparable investigations.

Tethered Swimming Apparatus

A tethered swimming apparatus was used throughout all phases of this study, with the exception of the pilot investigation. It was designed and utilized according to procedures outlined by Costill (1966), and Magel and Faulkner (1967). Upon entering the water, a belt was

TABLE 2

Physical and Maximal Performance Characteristics of Subjects

Measure	Mean	SD
Age (yr)	19.3	1.90
Height (cm)	176.3	5.15
Weight (kg)	77.9	8.51
Mean 200-Yard Swim Performance (sec)	111.9	2.21
$\dot{V}O_2max$ (ml/kg$\cdot$min^{-1})	51.6	7.30
$\dot{V}O_2max$ (l/min^{-1})	3.9	0.40
Peak Blood Lactic Acid (mg/dl^{-1})	119	12

placed around the waist of the subject. Attached to the belt were two nylon ropes which extended beyond the subject's feet and were fixed to the ends of a 1 in wooden dowel. Connected to the middle of the dowel was a nylon main rope which was threaded through two pulleys and linked to a weighted resistance. The apparatus was mounted on the pool deck adjacent to the pool.

Preliminary Test

The purpose of the Preliminary Test was to obtain maximal physiological values for classification of the subjects and to determine the extent to which the experimental trials induce maximal conditions. In addition, the maximal workload attained was used to prescribe the workload at which the subject would swim during the experimental trials.

Each subject was given two practice trials on the tethered swimming apparatus to reduce the chance of systematic variation in performance due to learning of tasks. The practice trials consisted of two 3-min swims at individually prescribed workload intensities.

The Preliminary Test consisted of a maximal intermittant tethered swimming trial to determine maximal parameters for each experimental subject. A series of 3-min workloads were interposed with 3-min rest intervals. Workload increments were increased by multiples of 2.5 lbs and work was continued until voluntary exhaustion.

After entering the water and being fitted to the equipment, the subject was asked to swim several strokes of breastroke to locate a diving brick used to mark the proper position to be maintained by the swimmer. At this time, an initial stress was placed on the tethered swimming apparatus to eliminate any excessive force acting on the swimmer or the apparatus. The test began with the subject swimming the front crawl. During the rest periods between workloads, swimmers were reminded to perform maximally. Swimming was conducted under tethered conditions described earlier in this chapter, during which measures were obtained on the dependent variables on oxygen uptake, ventilation, and respiratory exchange ratio and post exercise blood lactic acid. Each test was terminated according to the subject's perception of voluntary exhaustion as indicated by his feelings of nausea, dizziness and other fatigue symptoms.

Description of and Criteria for Acceptance of Dependent Measures

Specific physiological variables were observed and recorded throughout all experimental testing in this investigation. The variables of oxygen uptake, ventilation, and respiratory exchange ratio were recorded during each tethered swimming test. Peak post-exercise blood samples were obtained at 230 and 290 sec intervals into recovery.

Oxygen Uptake

Oxygen uptake values were determined during the final minute of each workload during the preliminary test, and during the final 60 sec of each 110 sec experimental trial. The value was computed using expired air samples which were analyzed for gas content, and minute ventilation which was obtained by a ventilation meter on the pool deck. The value for each test was accepted, providing the swimmer displaced the appropriate weight by maintaining proper position over the diving brick for the alloted time.

Pulmonary Dynamics

Pulmonary ventilation, respiratory frequency (f) and tidal volume (V_t) values were also determined in connection with the $\dot{V}O_2$ procedure during each tethered swimming test. Data from trials were accepted unless the swimmer failed to use the proper respiratory frequency for more than two consecutive cycles or any four cycles. To verify that subjects used the requested ventilatory pattern, two technicians observed and recorded the breathing frequency as well as the number of stroke cycles, respectively, during the final 60 sec of each trial. Respiratory exchange ratio was calculated from the $\dot{V}O_2$ data.

Blood Lactic Acid

Blood lactic acid samples were collected at 230 and 290 sec following the experimental trials, under the assumption that peak values would be obtained therein (Knuttgen, 1962). Data from the trial were considered valid if the measured lactic values differed by no more than 10% of each other. If values differed by more than 10%, the trial was then repeated within one week of the rejected trial.

Experimental Tests

After the Preliminary Test was concluded, the experimental phase of the study was conducted. The experimental tests consisted of four simulated 200-yard freestyle sprint swims each administered in individual trials on four separate days. Subjects were required to swim two trials using Experimental Condition 1 (EC_{1a}, EC_{1b}), which was associated with relative tachypnea, wherein the subject was required to breathe every stroke. The remaining two trials were conducted under Condition 2 (EC_{2a}, EC_{2b}), which was associated with relative hypopnea, wherein the swimmer breathed every alternate arm stroke. Breathing patterns were randomly assigned to each subject.

In each of the four experimental trials the subject swam under tethered conditions for 110 sec. The selected time interval for swimming was established to approximate "AAA" time standards chosen by the

Amateur Athletic Union (1978) for the 200-yard freestyle for the approximate age of the participants utilized in this study and, as such, is a practical criterion for success in competitive swimming. To induce near maximal effort, and thus approximate the effort of a competitive swim, 95% (± 2.5 lbs) of the weight displaced during the Preliminary Test was attached to the tethered swimming apparatus during the experimental trials. Expired air samples, ventilation data, and oxygen uptake samples were collected during the final 60 sec of each 110 sec swim trial, and blood lactic acid samples were obtained at intervals of 230 and 290 sec into recovery.

Laboratory Measurement Techniques

The measures obtained during the preliminary and experimental trials were analyzed according to specific procedures. Expired air and ventilation were collected and measured using gas analysis procedures as outlined by Costill (1966). Blood samples were collected and lactic acid concentration was determined using blood lactic procedures as outlined by Sigma Chemical (1976).

Gas Analysis Procedure

Prior to each test, the subject was fitted with a plexiglass headpiece containing a Wilmore-Costill breathing valve which, in turn, was fitted with a rubber mouthpiece. Attached to this apparatus were two 1½ inch diameter Warren-Collins flexible hoses which carried inspired and expired air to and from the breathing valve. The hoses were suspended directly over the swimmer's head using a metal rod to keep them from impeding the swimmer's stroke.

During both the preliminary and experimental trials, minute ventilation (Ve_{STPD}) was measured from inspired air flow data obtained using a Parkinson-Cowen CD-4 Dry Gas meter. Expired gas was collected in 120 liter meterological balloons and subsequently analyzed for oxygen and carbon dioxide content on Beckman OM-11 (O_2) and LB-2 (CO_2) automatic electronic respiratory gas analyzers. Gas analyzers were calibrated prior to and periodically throughout gas analyses. The Ve values were corrected for atmospheric conditions and standard temperature and pressure through calculations based on measurements of air temperature (^oC), barometric pressure (mmHg) and water vapor pressure in air (mmHg) which were taken in the test area.

Blood Lactic Acid Procedures

At 230 sec following the termination of each experimental swim test, a blood sample was collected for micro-determination of whole blood lactic acid. Blood samples were drawn from a pre-warmed finger tip in 100 μl calibrated Corning Disposable Microliter Pipets. The blood was immediately transferred to a centrifuge tube containing 1.1 ml of an 8% perchloric acid solution and mixed thoroughly to prohibit conversion of lactate to pyruvate. The contents were then refrigerated until lactic acid determination could be made (Appendix F). Under refrigeration specimens treated in this manner are stable for a period of 1 week (Sigma, 1976).

At the end of each test day all blood samples were centrifuged in a Damon International Model HN-S Centrifuge for 10 min at 3000 rpm to precipitate blood protein from the lactate containing supernatent. The clear supernatent was then transferred into vials containing nicotinamide adenine dinucleotide (NAD) and diluted with glycerine buffer, lactate dehydrogenase, and water (Sigma, 1976). After a thorough mixing, all samples and standards were incubated for 30 min at 37°C in a Thomas Constant Temperature Water Bath. Standards and unknowns were then read on the Hitachi Model 102 Digital Spectrophotometer at 340 nonometers (nm).

The spectrophotometer was calibrated each day just prior to the analyses. The standard curve used in the present study and derived from the Hitachi Spectrophotometer is in Appendix G. For calibration, blanks and standards with known lactate concentrations were prepared by diluting a 40% lactic acid diluted standard with water, and by mixing NAD vials with glycerine buffer, lactate dehydrogenase, and water (Sigma, 1976). After calibration, experimental samples were measured spectrophotometrically for lactate content.

Data Analysis Procedures

Within Conditions

To determine the degree of reproducibility within each experimental condition (e.g., EC_{1a}, EC_{1b}, EC_{2a}, EC_{2b}) Pearson product-moment correlations were computed for oxygen uptake, respiratory exchange ratio, ventilation, and blood lactic acid. Within each condition, analyses were also conducted for stroke and breath frequency.

Between Conditions

To determine if physiological responses between Experimental Condition 1 and 2 were significantly different ($\underline{p} < .05$) Hotelling's $\underline{T}^2$ for paired samples was used (Senter, 1969). Through this procedure, the values for $\dot{V}O_2$, $\dot{V}e_{STPD}$, and blood lactic acid were used to generate a single response score which represented the linear combination of the variables. If significant Hotelling's $\underline{T}^2$ were observed then simultaneous confidence intervals were established to determine which dependent variables differed across breathing methods.

Summary

In summary, a pilot investigation was employed prior to the experimental phase of the investigation to determine the validity of capillary blood samples for the use of micro-determination of blood lactic acid. It was concluded that capillary blood samples as obtained in the pilot investigation were valid for blood lactic acid determination and therefore were used in this study.

Ten male subjects participated in the experimental phase of this investigation and met specific criteria for participation. All testing was conducted using a tethered swimming apparatus.

A Preliminary Test was employed to obtain the maximal physiological parameters of all subjects, and to prescribe the workload used for the experimental trials. The dependent variables measured included oxygen uptake, ventilation, respiratory exchange ratio, and blood lactic acid. Criteria were established for their acceptance. When swim trials were rejected due to criteria failure, an identical trial was conducted within one week.

After the Preliminary Test was completed, the experimental trials were conducted, to determine the effects of two breathing patterns on selected physiological responses to a simulated 200-yard freestyle swim. For the assessment of the oxygen uptake, ventilation, respiratory exchange ratio, and blood lactic acid, gas analysis and blood lactic acid procedures were followed.

Data analysis procedures consisted of Pearson product-moment correlation to determine the degree of reproducibility within experimental conditions. Multivariate analyses were used to determine if significant changes occurred in the observed physiological responses as a result of two breathing conditions.

CHAPTER 4

RESULTS AND DISCUSSION

The results of this study have been organized into three sections for the following presentation. In the first section, reliability estimates and limits of reproducibility for each of the dependent variables within each breathing condition are presented. The second section pertains to the results of the Hotelling's $\underline{T}^2$ analysis for the differences between the two experimental conditions. The third section contains a discussion on performance and training implications. Individual data for subjects on each dependent measure within both conditions are presented in Appendixes H and I.

Reproducibility Within Breathing Conditions

The mean and intra-condition reliability estimate for the dependent variables measured within each experimental trial are presented in Table 3. Oxygen uptake, ventilation, and blood lactic acid were found to have reliability coefficients of .81 or higher in both Condition 1 and 2. The respiratory exchange ratio was found to be reliable under Condition 1 ($\underline{r}$=.91), however, under Condition 2, unacceptable limits were observed ($\underline{r}$=.39). The unacceptable reliability estimate for the respiratory exchange ratio may have been the result of one subject's values which varied substantially from the values obtained from the other subjects (see Appendix H, subject 4). All reliability coefficients were judged acceptable providing the $\underline{r}$ value was significantly different from ones at the .05 level of probability.

TABLE 3

Mean Standard Deviation and Reliability Coefficient for Dependent Variables Under Condition 1 and 2

Measure	Condition 1					Condition 2				
	T_1	SD	T_2	SD	r^a	T_1	SD	T_2	SD	r^a
$\dot{V}O_2$ (l/min^{-1})	3.37	.32	3.46	.31	$.81_b$	2.72	.34	2.74	.31	$.82_b$
$\dot{V}O_2$ $(ml/kg \cdot min^{-1})$	43.90	4.16	44.48	4.46	$.91_b$	35.35	6.18	35.74	4.74	$.93_b$
Respiratory Exchange Ratio	1.06	.12	1.03	.13	$.91_b$	.99	.11	1.06	.13	.39
Ve_{STPD} (l/min^{-1})	91.51	8.75	90.33	9.83	$.85_b$	59.75	9.86	60.40	7.82	$.81_b$
Blood Lactic Acid (mg/dl^{-1})	89	10.32	86	8.25	$.95_b$	68	11.61	71	10.36	$.89_b$

[a] = reliability coefficient as determined by Pearson product-moment correlation.

b = significant at .01 level.

Condition 1

Under Condition 1, each subject was required to breathe every left or right arm stroke during two 110 sec trials of simulated 200-yard freestyle swimming. To estimate test reliability, the Pearson product-moment correlation technique was employed on the dependent variables of oxygen uptake, respiratory exchange ratio, ventilation and blood lactic acid in trial 1 and 2 (Senter, 1969). Values for individual data in Condition 1 are in Appendix I.

$\dot{V}O_2$ (l/min^{-1}). The $\dot{V}O_2$ (l/min^{-1}) values observed in Condition 1, where the subjects performed under relative tachpnea, were found to be reliable (r=.81, p < .01). The coefficient of determination indicated a substantial degree of reproducibility (r^2=.66).

$\dot{V}O_2$ (ml/kg·min^{-1}). The $\dot{V}O_2$ (ml/kg·min^{-1}) was found to be reliable (r=.91; p<.01), and as indicated by the coefficient of determination (r^2=.83), highly reproducible. When compared to the value obtained for $\dot{V}O_2$ (l/min^{-1}), it is evident that the $\dot{V}O_2$ (ml/kg·min^{-1}) measured during swimming was a more reliable measure than $\dot{V}O_2$ (l/min^{-1}). The implications of this finding suggest that in terms of reproducibility, the $\dot{V}O_2$ (ml/kg·min^{-1}) is a more stable parameter than $\dot{V}O_2$ (l/min^{-1}). Therefore, the $\dot{V}O_2$ (ml/kg·min^{-1}) may be considered the more useful descriptor of aerobic metabolism during a stressful 200-yard freestyle swimming.

Respiratory Exchange Ratio. The reliability coefficient for the respiratory exchange ratio was calculated to be .91 (p<.01), with a coefficient of determination of .83. These values indicated that the respiratory exchange ratio was highly reproducible.

Ventilation. The reliability coefficient for ventilation was .85 ($p<.01$), and the coefficient of determination was computed to be .72. Ventilation, therefore, was considered to have a substantial degree of reproducibility.

Blood Lactic Acid. Blood lactic acid values were found to be highly reliable ($r=.95$; $p<.01$). The coefficient of determination indicated that 90% of the variation could be accounted for by the measurement technique.

Condition 2

Under Condition 2, wherein the subject was required to swim breathing on alternate arm cycles only, two 110 sec trials of simulated 200-yard freestyle swimming were performed to determine the reliability estimates for the same dependent variables measured in Condition 1. To obtain the reliability estimates, Pearson product-moment correlation was employed. Individual data for Condition 2 are in Appendix H.

$\dot{V}O_2$ (l/min^{-1}). The reliability coefficient for $\dot{V}O_2$ (l/min^{-1}) was .81 ($p<.01$), with a coefficient of determination of .67. It is evident that $\dot{V}O_2$ (l/min^{-1}) was a reliable measure, evidencing the same level of reproducibility seen in Condition 1.

$\dot{V}O_2$ (ml/kg·min^{-1}). The reliability coefficient for $\dot{V}O_2$ (ml/kg·min^{-1}) was .93 ($p<.01$), with a coefficient of determination of .86. This measure was therefore considered to be highly reproducible. It is also evident that the $\dot{V}O_2$ (ml/kg·min^{-1}) was a more stable variable than $\dot{V}O_2$ (l/min^{-1}) under Condition 2.

Respiratory Exchange Ratio. The reliability coefficient of the respiratory exchange ratio was calculated to be .39 which falls well below the acceptable limits of reliability. The values of one subject, which varied substantially from the values observed in other subjects, may have contributed to the instability of this variable under this condition (Appendix H, subject 4). However, subsequent calculation of the Pearson product-moment correlation, without the subject's values still indicated a low degree of reproducibility ($\underline{r}$=.60; $\underline{r}^2$=.36). Therefore, to maintain the integrity of this investigation, the respiratory exchange ratio was excluded from further analyses.

Ventilation. The reliability coefficient for ventilation was .81 ($\underline{p}<.01$), with a coefficient of determination of .66. These findings indicate that ventilation had substantial limits of reproducibility.

Blood lactic acid. The reliability coefficient for blood lactic acid was .89 ($\underline{p}<.01$) with a coefficient of determination of .79. These values indicate that blood lactic acid was a highly reliable measure within this condition.

In summary, the variables of oxygen uptake, blood lactic acid, and ventilation within Condition 1 and 2 were highly reproducible. Under Condition 1, the respiratory exchange ratio was also found to be reliable ($\underline{r}$=.91), however, under Condition 2 the variable was found to be unstable ($\underline{r}$=.39). The unacceptable respiratory exchange ratio may have been largely affected by the results of one subject, whose inter-trial values differed between the trials to a larger extent than the other subjects.

Comparison of Experimental Breathing-Swimming Conditions

The major purpose of this study was to determine the effects of two breathing patterns on selected physiological responses during a simulated 200-yard swim. Two experimental breathing patterns were used in this investigation, and all swimmers participated in each experimental trial.

Hotelling's $\underline{T}^2$ for dependent variables (Kramer, 1972) was employed to assess the significance of any observed differences on the linear combination of $\dot{V}O_2$, $\dot{V}e_{STPD}$, and blood lactic acid between Experimental Conditions 1 and 2. This analysis indicated that there was a significant difference between the two experimental conditions ($\underline{T}^2=47.68$; $\underline{p} < 01$). Therefore, simultaneous confidence intervals were calculated between the means of the physiological variables for each condition to determine which of the variables contributed to the significant difference. If the simultaneous confidence intervals did not span the point zero, then the difference between the mean of Condition 1 and 2 was statistically significant ($\underline{p} < .05$). If the intervals did span the point zero, then this indicated that the observed difference was not statistically significant. As can be seen from Table 4, the calculated simultaneous confidence intervals indicated a significant difference between the means of each dependent variable (i.e., oxygen uptake, blood lactic acid, and ventilation).

$\dot{V}O_2$ (l/min^{-1})

As indicated in Table 4, a significant difference was observed between the means of $\dot{V}O_2$ (l/min^{-1}) in each condition. The difference, which amounted to .67 l/min^{-1}, may be attributed to the breathing pattern associated with each condition. During the relative tachypnea associated with Condition 1, biomechanical and physiological factors may

TABLE 4

Combined Mean and Standard Deviation for Each Experimental Condition, and Simultaneous Confidence Intervals for $\dot{V}O_2$. Ve_{STPD}, and Blood Lactic Acid For Each Condition

	Condition 1		Condition 2		Difference	Confidence Intervals
	Mean	SD	Mean	SD		
$\dot{V}O_2$ (l/min^{-1})	3.43	.30	2.73	.31	*0.67	(+.077, +.336)
$\dot{V}O_2$ ($ml/kg \cdot min^{-1}$)	44.19	4.22	35.52	5.35	*8.67	(+1.20, +5.22)
Ve_{STPD} (l/min^{-1})	90.92	9.99	60.25	8.42	*30.67	(+2.02, +8.80)
Blood Lactic Acid (mg/dl^{-1})	87	9	69	10	*17	(+2.47, +10.77)

*($p < .05$)

have accounted for the increased $\dot{V}O_2$ observed in this condition. Biomechanically, the relative tachypnea during swimming would increase the frequency of rotary movements of the head, legs, and torso, resulting in modifications in body attitude. Hay (1973) suggests that if the head, trunk, or legs deviate from the straight line direction in which the swimmer is moving, the effective cross-sectional area of the body is increased, resulting in increased form drag. Further, he suggests that the more numerous hesitations required for breathing may have led to increased leg and hip movement to counteract the rotary movement of the body. To account for the increased resistance incurred by the rotary movements of the body, a larger muscle mass may have been engaged, or more work may have been produced by the same muscles. In this connection, Cureton (1930) demonstrated that swim speed was inversely proportional to the number of breaths taken (i.e., swim speed increases when fewer breaths are taken). Karpovich (1933) reported that turning the head for breathing increased the resistance during swimming, thus reducing swim speed. Thus it is evident that the increased mechanical work required to compensate for the resistance incurred by the increased frequency of breathing in Condition 1 would be reflected in the $\dot{V}O_2$.

It is also possible that physiological factors affected the $\dot{V}O_2$. Ghesquire (1975), who considered buoyancy to play a minor role in swimming, identified body attitude and breathing time as factors which affect pulmonary and respiratory function. During the relative tachypnea of swimming, the time for inhalation may be shortened resulting in an altered composition of pulmonary gases. Under Condition 1, wherein a relative tachypnea was imposed, a reduced time for breathing may have lowered alveolar pO_2. In turn, a lowered alveolar pO_2 may have necessitated an increased ventilation (as compared to Condition 2) to maintain full O_2 saturation of blood hemoglobin. Although these circumstances are based on speculation, they may have resulted in increased metabolic demand of the respiratory muscles, thus partially contributing to the elevated metabolic demands in Condition 1 (i.e., increased $\dot{V}O_2$, and increased blood lactate). The biomechanical and physiological evidence from earlier studies cited above suggests that the observed difference in $\dot{V}O_2$ (l/min^{-1}) in each condition was the result of the increased breathing frequency required under Condition 1.

$\dot{V}O_2$ ($ml/kg \cdot min^{-1}$).

The difference between the means of $\dot{V}O_2$ ($ml/kg \cdot min^{-1}$) in Conditions 1 and 2 were significant ($\underline{p}<.01$). A factor which may have affected the $\dot{V}O_2$ value is the influence of water immersion on body density and the resultant effects of buoyancy on each subject. Since the amount of body fat and the distribution of fat around the body varies among subjects, Goff, et al. (1957), suggested that the $\dot{V}O_2$ ($ml/kg \cdot min^{-1}$) may not be a more descriptive variable than $\dot{V}O_2$ (l/min^{-1}) in assessing the metabolic demands incurred during swimming. When swimming, the relative fat content would alter body attitude creating changes in form resistance and metabolic requirements. As a result, Goff, et al. (1957), concluded that since an unknown buoyant weight was actually being pulled during swimming, the $\dot{V}O_2$ ($ml/kg \cdot min^{-1}$) did not reflect the oxygen consumption capacity of the individual per unit of true body mass. In view of this observation, it may be argued that the $\dot{V}O_2$ ($ml/kg \cdot min^{-1}$) does not accurately assess the metabolic demands during swimming. Nevertheless, the $\dot{V}O_2$ ($ml/kg \cdot min^{-1}$) values reported in this study were observed to be more stable in repeated trials under the same experimental condition than the $\dot{V}O_2$ (l/min^{-1}). In view of the absence of experimental data in the Goff, et al. (1957) study, and the stability of the $\dot{V}O_2$ ($ml/kg \cdot min^{-1}$) value observed in this study, the $\dot{V}O_2$ ($ml/kg \cdot min^{-1}$) was considered to be a better descriptor of the metabolic demands required during swimming.

Ventilation

The mean difference for the variable of ventilation was found to be statistically significant ($p<.05$). Ventilation, the product of respiratory frequency and tidal volume, may have been altered by either one of these parameters. As indicated in Table 5, the observed difference in the ventilation value in Conditions 1 and 2 amounted to 30.7 l/min^{-1}. A possible factor contributing to the increased ventilation in Condition 1 may have been the respiratory frequency. As illustrated in Table 5 and Appendix K, the respiratory frequency in Condition 1 almost doubled the respiratory frequency in Condition 2. However, it is also possible that the tidal volume affected the means of ventilation between conditions. Subsequent calculations of the tidal volume (V_t) indicated that under Condition 1, an average of 3.1 liters of air were inspired per breath, while under Condition 2, an average of 3.6 liters of air were inspired per breath. The relative hypopnea associated with Condition 2 may have induced the subjects to augment the total alveolar oxygen per breath by increasing the tidal volume.

The difference may also be attributed to a greater muscle mass required to maintain pulmonary gas exchange under the relative tachypnea associated with Condition 1, although such a Ve difference is not likely due to increased contraction of the respiratory muscles alone. In support of this supposition, it should be noted that the percentage of the maximum oxygen uptake obtained in

TABLE 5

Breath and Stroke Analysis Under Each Experimental Condition

	Condition 1		Condition 2	
	Relative Tachpnea		Relative Hypopnea	
	T_1	T_2	T_1	T_2
Number of Breaths/60 sec	29.6	33.5	16.8	17.6
<u>SD</u>	4.88	3.67	2.18	1.91
Number of Strokes/60 sec	30.2	33.6	33.1	33.6
<u>SD</u>	4.73	3.41	4.00	3.10
Breath/Stroke Ratio	.98	1.00	.51	.52

each experimental condition differed. According to Astrand and Rodahl (1970), there is a linear increase in ventilation as the percentage of maximal oxygen uptake is approached. As indicated in Appendix I, under Condition 1, approximately 87% of the maximal oxygen uptake values were attained, as opposed to 69% under Condition 2. It is speculated, therefore, that a partial contribution for the increased ventilation value observed in Condition 1 was the result of increased metabolic requirements indicated by the higher $\dot{V}O_2$ values in that Condition.

Blood Lactic Acid.

The difference between conditions for the mean of blood lactic acid was found to be statistically significant ($p < .05$). Under Condition 2, blood lactic acid values were 17 mg/dl^{-1} lower than the mean value of Condition 1. The difference may be reflected in the metabolic demands encountered under each experimental condition.

Under Condition 1, $\dot{V}O_2$ values were approximately 85% of maximal values, whereas the values under Condition 2 were approximately 69% of maximal values. Wasserman and Whipp (1973) have reported that blood lactic acid concentrations tend to remain low during submaximal exercise at intensities up to approximately 70% of the $\dot{V}O_2$max. After 70%, values were found to increase rapidly. Under Condition 1, where approximately 87% of the $\dot{V}O_2$max was attained, lactic acid values were found to approximate maximal lactate concentrations. Under Condition 2, where 69% of the $\dot{V}O_2$max was attained, the metabolic requirements may not have been high enough to induce a large degree of lactate production. It is possible that the increased lactate production in Condition 1 was the result of an increased muscle mass engaged to meet the increased metabolic requirements of augmented respiration, relative tachpnea, and head and trunk rotation. It is therefore suggested that the difference in blood lactic values could be attributed to the degree to which the $\dot{V}O_2$ in each condition approached maximal values.

Linear Regression to Predict $\dot{V}O_2$ from Dependent Variables

To ascertain the degree to which the variables of blood lactate acid, respiratory exchange ratio, breath/stroke ratio, and ventilation contributed to the $\dot{V}O_2$ (ml/kg$\cdot$min^{-1}) values observed in Condition 1, simple linear and stepwise multiple regressions were calculated for the variables in Condition 1. Results of the analyses for each experimental condition can be seen in Table 6. It was found that under relative tachypnea where the total energy cost was high, the respiratory exchange ratio related to the $\dot{V}O_2$ more than any other dependent variable ($\underline{r}$=.71; $\underline{R}^2$=.51; $\underline{p}$<.05).

The same analysis was computed under Condition 2 on the variables of ventilation, blood lactic acid, and the breath/stroke ratio. Ventilation, which was substantially lower during relative hypopnia, was found to be the most related variable to $\dot{V}O_2$ ($\underline{r}$=.62; $\underline{R}^2$= 39; $\underline{p}$=.053).

When additional variables were added during relative tachypnea, the $\dot{V}e$ was found to be the next best related variable. However, the slight increase in $\underline{R}^2$ (i.e., $\underline{R}^2$=.62) was minimal and not statistically significant. Therefore, the $\dot{V}e$ was judged not to be a variable which could account for the variation in $\dot{V}O_2$ in this condition. Similarly, during relative

TABLE 6

Simple Linear Regression Formula for Predicting $\dot{V}O_2$ (ml/kg·min^{-1}) From Dependent Variables During Simulated Swimming

Equation	Predicted $\dot{V}O_2$ (ml/kg·min^{-1})		Regression constant		Regression coefficients and predictor variables	Coefficient of determination r^2	Standard error of estimate for equation	F
Relative Tachpnea $\dot{V}O_2$	Y	=	17.72	+	24.27R	.51	8.45	8.26 ($p<.05$)
Relative Hypopnea $\dot{V}O_2$	Y	=	11.5	+	$.40\dot{V}e_{STPD}$	.39	.18	5.12 ($p=.053$)
Difference Between Relative Hypopnea and Relative Tachpnea $\dot{V}O_2$	Y	=	4.89	+	$.12\dot{V}e_{STPD}$	.17	.10	1.63 ($p=.24$)

Predictor variables are: R=Respiratory Exchange Ratio; $\dot{V}e_{STPD}$=Ventilation hypopnia, the breath/stroke ratio was selected as the second variable. However, the $\underline{R}^2$ increased to a minimal extent ($\underline{R}^2$=.43) and the $\underline{R}^2$ was not found to be statistically significant.

Since substantial variations in $\dot{V}e$ and $\dot{V}O_2$ were observed when data from conditions 1 and 2 were contrasted, it was decided that changes in the subjects' ventilation between conditions should be examined with the differences observed in $\dot{V}O_2$ between conditions. Therefore, simple linear and stepwise regression were employed to analyze variations in the subjects' responses between experimental conditions.

The difference in values between conditions were calculated for each of the dependent variables. The $\underline{r}^2$ shown in Table 6 indicates that ventilation was found to account for a minimal degree of variation in $\dot{V}O_2$. The results indicate that measures not taken in this study largely accounted for the substantial difference in $\dot{V}O_2$ between conditions (i.e., biomechanical factors leading to increased metabolic rate in Condition 1.

Performance and Training Implications

The lower values obtained for oxygen uptake in Condition 2 indicate that swimming while breathing alternate stroke cycles is associated with lower energy requirements than breathing every stroke cycle. The values of blood lactic acid, and ventilation which were also lower under Condition 2, support this premise. These findings strongly suggest that breathing on alternate stroke cycles enables the swimmer to maintain a given pace with less effort than would be required when breathing every stroke cycle, or that under high workloads swimmers breathing every stroke would reach fatigue earlier. In addition, the biomechanical implications indicate that relative hypopnea will reduce the resistance incurred by movement of the head and torso required to breathe. It is therefore suggested that performance will increase if hypopnic breathing is utilized.

The high blood lactic acid values in both conditions indicated that the 200-yard freestyle is primarily an anaerobic event. On the other hand, the high $\dot{V}O_2$ values suggest that substantial aerobic metabolism was also involved. These values appear to be in agreement with Kedrowski (1976) who reported that the 200-yard swim utilized an equivalent percentage from each energy source. His conclusion was predicated on the amount of time required to swim the event. It is suggested that the national caliber swimmers, who require less time to swim the event than the subjects utilized in the present study, would perhaps utilize a greater percentage of anaerobic metabolism, while age group swimmers, who are generally slower, would utilize relatively greater aerobic metabolism.

It was previously suggested that the 200-yard freestyle event utilized both aerobic and anaerobic metabolism. Kedrowski (1976) reported that during swimming of approximately 2 min duration, equivalent sources of both aerobic and anaerobic metabolism were used. Since the extent to which aerobic and anaerobic metabolism were engaged cannot be determined without sophisticated experimentation, the use of both methods during training for 200-yard freestyle competition is recommended. It is possible that the $\dot{V}O_2$ may be affected by the respiratory frequency. Therefore, the development of specific muscles to turn the head and torso, would perhaps reduce regional blood flow serving those areas thus enabling more blood for the muscles involved in propulsion.

The term "hypoxic breathing" has been used frequently by leading practitioners, yet its use is misleading when referred to during swimming. The term "hypoxic" refers to the reduction of oxygen to the tissues per liter of blood, and is often associated with the inhalation of air containing a low oxygen content (Astrand & Rodahl, 1970). Hypopnic breathing, however, refers to a reduction in the respiratory frequency, and during swimming this is accomplished voluntarily.

The extent to which hypopnic breathing should be utilized in training is of critical importance. Although it has not been demonstrated experimentally, it has been speculated that hypopnic breathing during training would increase the ability of the tissues to extract oxygen from the blood (Counsilman, 1975). It is also possible during hypopnea that the body's capacity to tolerate anaerobic metabolism may be increased.

In addition, the principle of specificity suggests that if hypopnic breathing is the preferred method of breathing during 200-yard competitive swimming, it should also be employed during swim training. The implications of the findings indicate that although swimming during relative tachypnea elicits higher physiological metabolism, it does not elicit specific physiological responses to stressful 200-yard swimming, and therefore, the use of hypopnic breathing is recommended during swim training.

Summary

It was found that oxygen uptake, ventilation, and blood lactic acid were highly reproducible within each experimental condition. Respiratory exchange ratio was found to have substantial limits under Condition 1, however, under Condition 2, unacceptable limits were observed. Reliability coefficients for all variables, except the respiratory exchange ratio in Condition 2, were .81 or higher.

Hotelling's $\underline{T}^2$ for the linear combination of dependent variables indicated a significant difference in physiological responses between Condition 1 and 2. Subsequent application of simultaneous confidence intervals conducted on the dependent variables indicated a significant difference for each of the dependent variables (i.e., $\dot{V}O_2$, blood lactic acid and ventilation).

Simple linear and stepwise regression analyses were computed to ascertain the degree to which the dependent variables contributed to the $\dot{V}O_2$. Under Condition 1, the respiratory exchange ratio was found most related to the $\dot{V}O_2$. Under Condition 2, ventilation was found to be most related to $\dot{V}O_2$. Since significant differences in the dependent variables were observed between conditions, regression analysis was computed on the difference in the dependent variables between conditions. The results indicated that factors not measured in the present study were largely responsible for the higher $\dot{V}O_2$ seen in the condition where relative tachypnic breathing was employed.

The findings suggest that breathing on alteranate stroke cycles may enable the swimmer to perform under higher work levels, or maintain a relative swimming pace with less effort, than when breathing every stroke cycle. It was also suggested that 200-yard swimming requires energy from both aerobic and anaerobic metabolism.

Due to the physiological and biomechanical implications, the use of alternate breathing was recommended during performance. The use of both aerobic and anaerobic types of training was suggested; however, since the degree to which aerobic and anaerobic energy for the 200-yard event could not be quantified.

CHAPTER 5

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

Since coaches have suggested the use of alternate breathing patterns for competitive events of 200 yards or less, the analysis of physiological variables under these conditions was deemed important. Therefore, this study attempted to assess the effects of two breathing patterns (i.e., breathing every arm stroke, or every alternate arm stroke) on oxygen uptake, blood lactic acid, respiratory exchange ratio, and ventilation during near-maximal simulated 200-yard freestyle swimming.

Prior to the experimental trials, a pilot investigation and a Preliminary Test were administered. The pilot investigation attempted to determine the validity of capillary blood for the use of microdetermination of blood lactic acid. The results indicated that capillary blood samples closely resembled venous blood, although capillary samples were found to have a greater degree of variability than venous samples. The Preliminary Test was conducted to determine the maximal capacity for each individual and to establish a workload which would elicit near-maximal responses for the experimental trials. The results of the Preliminary Test indicated that the subjects used in the present investigation compare favorably in metabolic capacity, swim performance and physical characteristics with subjects previously investigated in swimming research.

The experimental phase of the study consisted of four simulated 200-yard freestyle swim trials each administered on separate days. Two trials were conducted under Condition 1, wherein the subject breathed every stroke. The remaining two trials were conducted under Condition 2, wherein the subject breathed during alternate swim cycles. Criterion were established for the acceptance of responses for each dependent variable, and measurements were monitored by technicians on the pool deck. Trials were repeated within one week if a given criterion was not accepted. To simulate 200-yard freestyle performance each swimmer exercised under tethered swim conditions at pre-determined workloads for 110 sec. To induce near maximal effort, 95% of the weight displaced during each subject's Preliminary Test was attached to the tethered swimming apparatus during the experimental trials. Breathing patterns, wherein the swimmer breathed every or alternate arm strokes, were assigned in order that experimental trials could be administered randomly.

Within condition analyses indicated that the dependent variables in each condition were reliable ($\underline{r}$=.81; $\underline{p}$<.01), with the exception of respiratory exchange ratio in Condition 2 ($\underline{r}$=.39). It is possible that the values of one subject, whose values varied substantially from the observed values of the other subjects, may have contributed to the instability of this variable in Condition 2. Therefore, respiratory exchange ratio was excluded from further analyses.

Using multivariate statistics, it was found that there was a significant difference in the physiological variables as a result of the breathing patterns ($\underline{p}<.01$). Using simultaneous confidence intervals, it was found that oxygen uptake, blood lactic acid, and ventilation were the dependent variables which caused the difference. Subsequent analyses using stepwise regression were employed to predict the $\dot{V}O_2$ (ml/kg$\cdot$min^{-1}) in each experimental condition. Under Condition 1, the respiratory exchange ratio was found to relate more to the $\dot{V}O_2$ than any other dependent variable. Under Condition 2, ventilation was found to be more related than any other dependent variable. Using the same analysis to predict changes in $\dot{V}O_2$ between conditions, it was found that the breathing pattern associated with each condition was not related to changes in $\dot{V}O_2$ between conditions.

The findings suggested that breathing on alternate strokes was associated with lower energy requirements than breathing every stroke. Thus, it was suggested that during alternate breathing, the swimmer could maintain a relative pace with less effort, or reach fatigue later under work of higher intensity than breathing every stroke. The findings also indicated that both aerobic and anaerobic metabolism are employed during the 200-yard freestyle.

During performance, therefore, it was suggested that the swimmer breathe every alternate stroke. During training, the implications were that aerobic swimming could be used to elicit specific responses to breathing in the musculature in the upper body. The use of anaerobic swimming during both high and low intensity exercise was also suggested. During low intensity, tolerance to CO_2 and increased pulmonary gas exchange during breath holding, factors evident during 200-yard swimming, may be encouraged. During high intensity swimming, a higher tolerance to lactic acid levels may be encouraged.

Conclusions

Based on the results of this experiment, the following conclusions were made:

1. Capillary blood obtained by finger puncture is valid for the use of micro-determination of blood lactic acid. In comparison to venous samples, however, capillary samples were found to have a greater degree of variance.

2. Breathing on alternate strokes produces lower energy requirements for the variables of oxygen uptake, ventilation, and blood lactic acid, then when breathing every stroke.

Recommendations

Based upon this study, the following recommendations for future research are made:

1. Use bilateral breathing, a method of breathing every 1 ½ strokes, to determine how physiological variables are affected by moderate breathing restrictions.

2. Train swimmers using different breathing patterns and compare pre- and post-season results, since it is not known how training will effect hypoxic breathing.

3. Select swimmers on the basis of training and/or use of hypoxic breathing during training, since these variables would be likely to affect responses under those experimental breathing conditions.

4. Further study should attempt to determine the energy cost of breathing during swimming, since the biomechanical and physiological implications indicate greater metabolic requirements under relative tachypnea.

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APPENDIX A

VALIDITY OF CAPILLARY BLOOD LACTIC ACID

	BLOOD LACTIC ACID	
		mg/dl^{-1}
Subject	Capillary Sample	Venous Sample
1	78	94
2	68	74
3	80	68
4	80	88
5	180	164
6	116	106
7	124	132
8	112	100
9	48	80
X	98.4	100.7
SD	37.1	28.7

$r=.93$; $p < .01$

APPENDIX B

INFORMED CONSENT

I, ______________________, do hereby voluntarily agree and consent to participate in an exercise testing program conducted by the personnel of the Human Performance Laboratory of the Division of Health and Physical Education of Virginia Polytechnic Institute and State University, to study my physical fitness.

To evaluate my cardiorespiratory endurance, I voluntarily agree to perform a tethered swimming test. I understand that the procedure will be to swim a series of 3 min workloads followed by 3 min rest intervals until voluntary exhaustion. Each new workload will be increased by multiples of 2.5 lbs. Subsequent swims will be 110 sec long at 95% of maximal capacity. I understand that I will swim until a state of fatigue is approached. Fatigue is defined as the point where work has become <u>very</u> hard as indicated by my feeling of effort or discomfort, dizziness, nausea, breathlessness, chest pain, or any other negative symptoms which I report to the testor. I further understand that under certain conditions I will be breathing under hypoxic conditions, and that expired air will be collected and oxygen uptake determined.

I also voluntarily agree to allow trained personnel of the Human Performance Laboratory to collect 100 microliter blood samples by finger puncture for the determination of blood lactic acid. I also agree to allow a Registered Nurse to collect 5 ml of venous blood for reliability of lactic acid determination.

Risks of the test include occasional changes in the rhythm of the heart rate and the possibility of extreme changes in blood pressure. There are slight possibilities of fainting and heart attack; these chances are increased if a hot shower is taken shortly after strenuous exercise testing; however, these risks are reduced significantly for athletes currently participating in training. Competent test supervision protects against injury by providing appropriate precautionary procedures. If these precautions are insufficient, a telephone is available which would be used to call the local hospital for emergency service.

Benefits of testing include estimation of physical working capacity and determination of anaerobic metabolism during a simulated 200-yard swim which will benefit coaches in providing training specific to this event.

I understand that I may abstain from participation in any part of the testing or withdraw from the program should I feel the activities might be injurious to my health. I understand that my test and class data of a personal nature will be held confidential. Data used for research purposes may only be used when not identifiable with me. I further understand that approval to conduct this study has been obtained from the Human Subjects Committee at Virginia Polytechnic Institute and State University.

I have read the above statements and have had the opportunity to ask questions.

Date: ______________________ Time: ______________________ AM/PM

Participant Signature: ____

Witness: ____
HPER Personnel

APPENDIX C

PARTICIPANT INSTRUCTIONS FOR EXERCISE TESTING

Prior to reporting for your tests, it is essential that you adhere to the following guidelines:

1. See your family physician before your scheduled test session. It is generally desirable for all people to have a medical examination once each year. This check-up should include, among other measures, a complete 12-lead electrocardiogram. Bring a signed statement of your physician, indicating that you are healthy and that there is no medical reason which would preclude your participation in exercise testing. Failure, on your part, to obtain a medical check-up, will not exclude you from the program. However, this medical examination is a precautionary procedure that is included for your protection. If a physician contra-indication is reported by the physician, he will recommend that you not participate. We will not allow you to enter the testing under those conditions. If you elect to participate without a physical exam, your risks, as described in the informed consent form, may increase. Therefore, it is encouraged that you comply with this request, so that the risks can be kept as small as possible.

2. Avoid eating any food during the 4 hours preceding your test. (For example, if scheduled for an 8:00 a.m. test, don't eat breakfast before the test.)

3. Before retiring the evening before your test, consume 3 glasses of clear fluid (juice, water, etc.). If your test is scheduled after 10:00 a.m., also drink 1-2 glasses of water before reporting to the laboratory.

4. Sleep 7-8 hours the night before your test.

5. Empty your bladder and bowels before reporting to the laboratory.

6. Don't consume any alcoholic beverages or non-prescription drugs during the 12 hours preceding the test. Don't use tobacco during the 3 hours before the test.

7. Bring your informed consent form, unsigned, to the laboratory. You may wish to ask questions about the test prior to giving your written consent.

APPENDIX D

MAXIMAL PERFORMANCE VALUES ON PHYSIOLOGICAL AND CARDIOVASCULAR VARIABLES

	$\dot{V}O_2$				
Subject	l/min^{-1}	$ml/kg \cdot min^{-1}$	mg/dl^{-1}	R	l/min^{-1}
1	4.30	45.53	136	0.96	111.0
2	4.11	58.32	132	0.94	121.0
3	3.55	48.79	104	1.12	110.9
4	3.78	51.02	96	0.99	91.0
5	4.59	67.35	112	0.90	110.5
6	3.72	40.95	124	0.89	125.5
7	3.86	54.62	120	0.91	96.8
8	3.51	44.11	110	0.93	107.8
9	3.54	50.21	122	0.82	84.0
10	4.60	55.35	130	0.92	98.5
X	3.96	51.62	119	0.94	105.6
SD	0.40	7.30	12	0.07	12.3

BLA=blood lactic acid

APPENDIX E

COMPARISON OF MEAN CHARACTERISTICS OF SUBJECTS TO COMPETITIVE SWIMMERS USED IN PREVIOUS PUBLISHED INVESTIGATIONS

Measure	Present Subjects	Dixon and Faulkner (1971)	Magel and Faulkner (1967)	McArdle *et al.* (1971)	Knowleton *et al.* (1978)
Age (yrs)	19.3	19.2	20.0		
Height (cm)	176.3	181.2	181.3		
Weight (kg)	77.9	73.7	76.3		
Performance Time (sec)	111.9		109.9		
$\dot{V}O_2$ max (l/min^{-1})	3.96	4.05	4.27		
$\dot{V}O_2$ max ($ml/kg \cdot min^{-1}$)	51.62		54.7	56.3	
Blood lactic acid (mg/dl^{-1})	119				146.7

APPENDIX F

BLOOD LACTIC ACID PROCEDURES

Calibration Procedures

1. To each of three NAD vials, pipet 2.0 ml of glycerine buffer using a 2.0 ml graduated blow-out type pipet.

2. Invert several times to dissolve NAD crystals. Combine all NAD solutions into a single flask.

3. To the combined solution, pipet 0.7 ml of water using a 1.0 ml graduated in .01 pipet; and 0.3 ml of lactate dehydrogenase. Mix well.

4. Label 6 cuvets from 1-6. To each cuvet pipet 1.0 ml of mixture in step 3 using a 1.0 ml graduated in .01 pipet. Using two 1.0 ml graduated in .01 pipets, add the following amounts of water and 40% lactic acid diluted standard to the respective cuvet: Cuvet 1, 2.0 ml of water, no lactic acid; Cuvet 2, 1.9 ml of water, 0.1 ml of lactic acid; Cuvet 3, 1.8 ml of water, 0.2 ml of lactic acid; Cuvet 4, 1.7 ml of water, 0.3 ml of lactic acid; Cuvet 5, 1.6 ml of water, 0.4 ml of lactic acid; and Cuvet 6, 1.5 ml of water, 0.5 ml of lactic acid.

5. Incubate all cuvets for approximately 30 min of 37°C or 45 min at 25°C.

6. Read absorbance values of Cuvets 2-6 using Cuvet 1 as a reference at 340 nm.

7. Plot these values vs. the following corresponding lactic acid concentration:

Cuvet	Absorbance	Blood lactic acid
1		6
2		12
3		24
4		36
5		48
6		60

Procedures for Micro-Determination of Capillary Blood Lactic Acid Samples

1. Label an appropriate number of test tubes as there are blood samples to be taken. Into each test tube pipet 1.1 ml of cold 8% perchloric acid (not provided with the Sigma Chemical Kit) using a 1.0 ml graduated in .01 pipet. Cover using sterilized wax paper.

2. To obtain capillary blood samples, subject should rest in the sitting position. Soak hand in warm water for 230 sec. At the end of this period, swab proximal end of finger with alcohol and wipe dry. Immediately puncture finger tip, and squeezing out distally, collect blood in 100 μl glass Corning Disposable Microliter Pipets. Quickly transfer blood into test tubes containing perchloric solution mentioned in step 1. Shake vigorously for 30 sec to insure complete protein precipitation. Lactic acid in the perchloric solution is stable for at least 1 week if refrigerated at 0-5^{o}C.

3. When blood lactic acid determination is to be made, centrifuge blood samples in perchloric solution for 10 min at 3000 rpm.

4. Determine the number of NAD vials required by the following formula:

$$\frac{\text{number of blood samples to be assayed +1}}{2}$$

   If the number obtained is not a whole number add one half to it for the actual number of vials required.

5. To each of the NAD vials required, as determined in step 4, add 2.0 ml of glycerine buffer using a 2.0 ml graduated blow-out type pipet; 4.0 ml of water using a 4.0 ml graduated blow-out type pipet; and 0.1 ml of lactic dehydrogenase using a .2 ml graduated in .01 pipet.

6. Invert NAD vials several times to dissolve NAD crystals. Combine all NAD solutions into a single flask.

7. Label an equivalent number of test tubes according to the number of blood samples taken. Label an extra test tube or Blank. Pipet 2.8 ml of the mixture from step 6 into each of the labeled test tubes using a 1 ml graduated in .01 pipet.

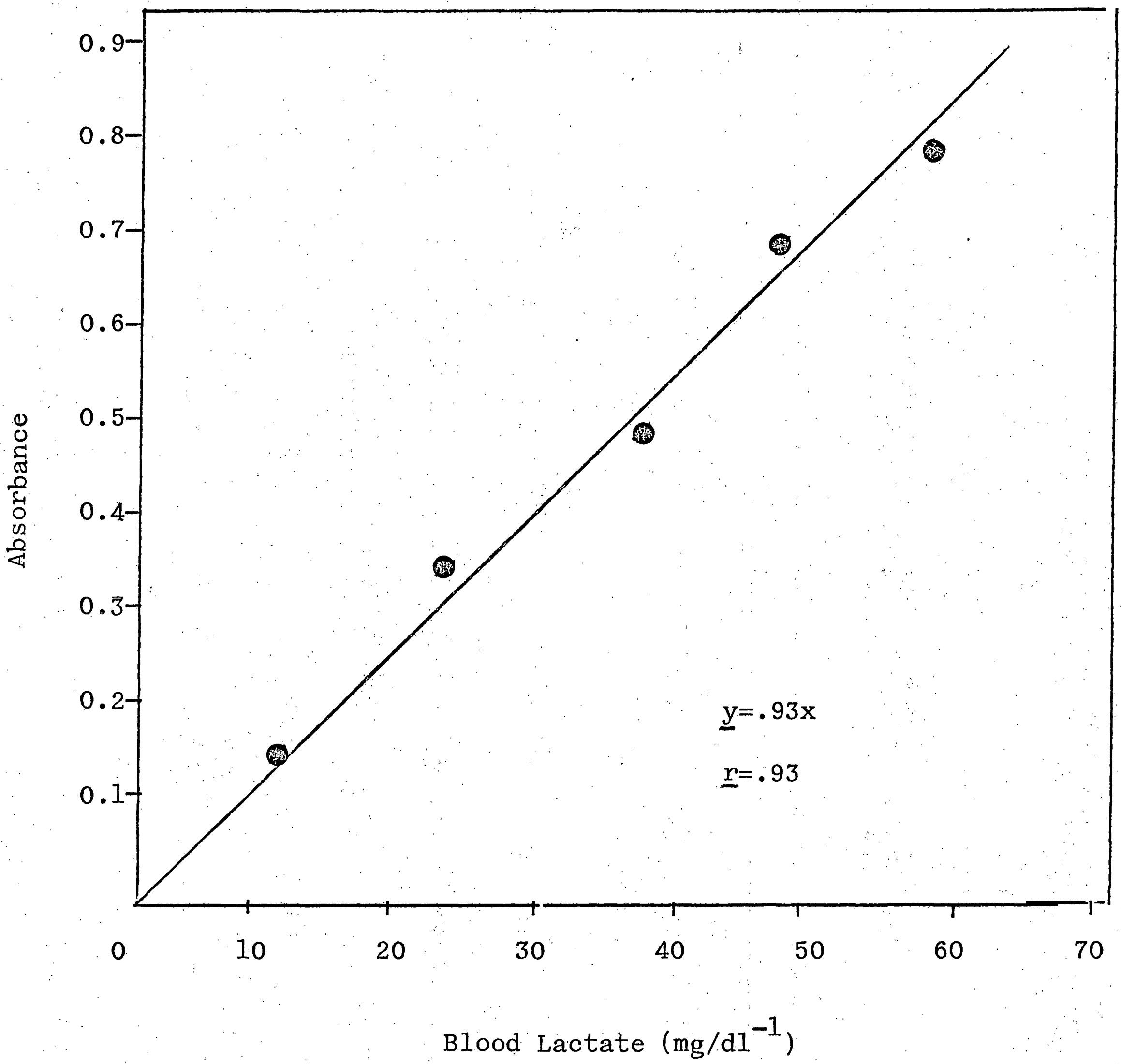
8. To the Blank, add an additional .2 ml of 8% perchloric acid using a .2 graduated in .01 pipet. To each of the labeled test tubes in step 7, add .2 ml of the respective protein-free solution prepared in step 2 using two 100 μl samples from an Eppendorf 100 μl automatic micro pipet.

9. Incubate all test tubes for approximately 30 min at 37^{o}C or 45 min at 25^{o}C.

10. Upon completion of incubation, calibrate spectrophotometer at 340 mm using the Blank as a reference. Read blood lactic acid samples in Absorbance mode. Reaction is complete if the absorbance rises by no more than .002 per minute. If the reaction is not complete, another incubation period of approximately 15 min should be allowed.

APPENDIX G

CALIBRATION CURVE FOR ABSORBANCE READINGS FOR BLOOD LACTIC ACID



APPENDIX H

EXPERIMENTAL CONDITION 1

	$\dot{V}O_2$									
	l/min^{-1}		ml/kg·min^{-1}		R		$\dot{V}e$ l/min^{-1}		BLA mg/dl^{-1}	
Subject	T_1	T_2	T_1	T_2	T_1	T_2	T_1	T_2	T_1	T_2
1	4.01	3.97	41.99	41.98	0.97	0.95	93.2	99.6	69	68
2	3.37	3.53	47.87	50.06	0.97	1.14	98.2	92.4	96	94
3	3.33	3.38	43.99	43.90	1.07	1.06	80.1	81.6	84	80
4	3.26	3.25	46.12	46.43	1.04	1.15	85.3	77.9	71	76
5	3.27	3.05	43.07	46.92	1.10	1.18	89.5	86.4	88	90
6	3.46	3.61	47.94	44.78	1.17	1.22	88.0	97.3	96	92
7	3.16	3.73	48.86	51.00	1.30	1.40	86.4	86.0	98	94
8	2.80	2.93	37.34	37.07	1.04	1.12	103.3	100.7	92	88
9	3.80	3.78	45.74	45.56	1.10	1.14	82.6	75.6	92	86
10	3.28	3.38	36.10	37.22	0.81	0.91	108.5	105.8	100	92
$\bar{X}$	3.43		41.19		1.01		90.2		87	
SD	0.30		4.22		0.32		9.9		9	

BLA=blood lactic acid

APPENDIX I

EXPERIMENTAL CONDITION 2

	$\dot{V}O_2$						$\dot{V}e$		BLA	
	l/min^{-1}		$ml/kg \cdot min^{-1}$		R		l/min^{-1}		mg/dl^{-1}	
Subject	T_1	T_2	T_1	T_2	T_1	T_2	T_1	T_2	T_1	T_2
1	2.88	3.17	30.51	33.53	0.95	0.94	53.6	57.8	62	72
2	2.99	2.92	42.49	41.90	1.13	1.20	68.7	65.3	90	88
3	3.04	2.89	41.77	39.67	0.94	1.16	74.9	67.7	56	54
4	2.72	2.90	36.77	39.36	0.95	1.27	48.5	51.7	60	66
5	2.52	2.26	36.93	33.14	0.99	0.99	53.7	46.1	70	72
6	3.09	3.01	43.64	42.79	1.02	0.98	76.2	68.5	56	60
7	2.99	2.89	37.63	36.39	0.97	0.85	62.3	66.7	58	63
8	1.95	2.16	25.95	28.63	1.06	1.11	46.2	50.6	78	87
9	2.64	2.52	31.78	31.72	0.89	0.91	58.5	66.7	84	76
10	2.37	2.73	26.02	30.26	1.07	1.16	58.5	62.9	64	69
$\bar{X}$	2.73		35.52		1.07		60.23		69	
SD	0.31		5.35		0.11		8.42		11	

BLA=blood lactic acid

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THE EFFECTS OF TWO BREATHING PATTERNS ON SELECTED PHYSIOLOGICAL PARAMETERS DURING A SIMULATED 200 YARD FREESTYLE IN MALE SWIMMERS

by

George Hamilton Bell Jr.

(ABSTRACT)

Ten male adolescent and young adult swimmers were examined to determine the effects of two breathing patterns on selected physiological parameters during a simulated 200-yard freestyle swim. Specifically, a comparison of oxygen uptake, blood lactic acid, ventilation and the respiratory exchange ratio responses to a timed swim were made under two experimental breathing conditions. The intensity of the experimental trials was maintained at approximately 95% of the subjects' maximal workload to induce maximal effort. The validity of capillary blood samples for the use of micro-determination of blood lactic acid was established prior to the preliminary and experimental trials. Maximal physiological parameters for each subject were then obtained during the Preliminary Test using a maximal intermittent tethered swimming test. The experimental phase of the study consisted of four 110 sec swims designed to simulate competitive 200-yard freestyle swimming. Two swims were conducted under Condition 1, wherein the subject swam breathing once every arm cycle. The remaining two swims were under Condition 2, wherein the subject swam breathing every alternate arm cycle.

Using Pearson product-moment correlation to determine within condition reliability for each dependent variable, it was found that

oxygen uptake, blood lactic acid and ventilation were reliable. Under Condition 1, the respiratory exchange ratio was also found to be reliable, however, under Condition 2, the reliability coefficient was considered unacceptable. Therefore, the respiratory exchange ratio was excluded from further analyses.

Hotelling's $\underline{T}^2$ was employed on the linear combination of oxygen uptake, ventilation, and blood lactic acid between conditions. This analysis indicated a significant difference ($\underline{p} < .05$) between conditions. Simultaneous confidence intervals indicated that oxygen uptake, blood lactic acid, and ventilation were the variables causing the difference.

Simple linear and stepwise regression were employed to determine the extent to which the dependent variables contributed to the $\dot{V}O_2$ (ml/kg$\cdot$min^{-1}) in each experimental condition. Under Condition 1, the respiratory exchange ratio was found to be closely associated with the $\dot{V}O_2$ in that condition. Under Condition 2, ventilation was found to be most closely associated with the lower $\dot{V}O_2$ observed in this condition. It was deemed important to determine the extent to which changes between conditions in the dependent variables contributed to changes in the $\dot{V}O_2$ (ml/kg$\cdot$min^{-1}) between conditions. It was found that the changes in ventilation contributed only a small portion to the changes in $\dot{V}O_2$ between conditions, which indicated that something other than the dependent variables was associated with the changes in $\dot{V}O_2$ between conditions.

During training and performance, the evidence suggests that under a given workload, greater metabolic capacity was required when breathing every stroke. In addition, higher intensities of work could be tolerated when breathing was done only during alternate strokes.