AN ABSTRACT OF THE THESIS OF

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Title: The Effects of Warm and Cold Water Scuba Finning on Cardiorespiratory Responses and Energy Expenditure

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This study was designed to determine cardiorespiratory and energy expenditure responses elicited by recreational divers while finning at a submaximal intensity (35% max) in cold (18°C) and warm (29°C) water with and without wet suits. Male divers (15) volunteered to participate in five experimental procedures. A maximal graded exercise tethered finning test, two submaximal (30 min.) finning tests in 29°C with and without wet suits, and two submaximal (30 min.) finning tests in 18°C with and without wet suits were performed. The variables measured were: breathing frequency (BF), minute ventilation ($\dot{V}_E$), oxygen consumption ($\dot{V}O_2$) respiratory exchange ratio (RER), heart rate (HR), and core temperature (CT). Caloric expenditure (kcal) was calculated from RER and $\dot{V}O_2$. A Four-Way ANOVA and repeated measures design was used to analyze the data. A significant ($p < 0.05$) Two-Way (suit x time) interaction was revealed for BF. A significant (p <

0.01) Three-Way (suit x temp. x time) interaction was revealed for V_E, VO_2, RER, HR, and CT.

An inverse relationship exists between BF and V_E when comparing dives with and without suits. Diving in 18°C with suits elicited higher BF and lower V_E than diving in 29°C without suits.

VO_2 increased significantly during three of the four dives. Diving without suits elicited higher VO_2 values though this was not significant in every case. Diving in a cold environment elicited higher VO_2 and V_E. The 18°C dive with suits elicited lower RER responses than the 29°C dives without suits. Cold stress dives elicited higher RERs, when compared to heat stress dives (not significant).

HR increased significantly during the four dives. Diving in 18°C with suits produced significantly higher HR's compared to 29°C diving without suits, suggesting that the suits provided adequate heat loss protection. CT significantly increased during three of the four dives. The significant decrease in CT occurred in the 18°C dive without suits. CT rose to a higher degree during the 18°C dive with suits than the 29°C dive without suits.

This research will be useful to physiologists, and diving instructors and associations. This study should increase knowledge about scuba diving and help to improve diving education and safety.

The Effects of Warm and Cold Water Scuba Finning on Cardiorespiratory Responses and Energy Expenditure

by

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DEDICATION

This work is dedicated to my parents, Don and Harriette, who have always been great in supporting me through any endeavor I have pursued. They helped me during this study by taking pictures, setting up the equipment, breaking the equipment down, and by performing some of the laboratory blood work until very late into the night.

Their constant encouragement and love have made my education and dreams possible. My parents have always provided me with love, friendship, and hope for the future. It is not so much what they have done for me as what they have enabled me to do for myself.

If I could.....Mom and Dad, give you one thing, I would give you the ability to see yourselves as I and others see you.... then you would realize what truly special people and parents you both are.

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Table of Contents

Page

Page

Page

List of Figures

List of Tables

THE EFFECTS OF WARM AND COLD WATER SCUBA FINNING ON CARDIOVASCULAR RESPONSES AND ENERGY EXPENDITURE

CHAPTER ONE

INTRODUCTION

Modern technology and scientific understanding of human tolerances have enabled people to overcome many previous physical limitations. In recent years men and women have made enormous progress in achieving the ability to experience events that were once considered impossible such as mountain climbing, skydiving, and various aquatic activities. Swimming was one field where humans lacked expertise. Humans now have the ability to swim for extended periods of time in the depths of the oceans.

Swimming is an activity in which the average individual can easily participate in and enjoy. With the accessibility and abundance of large bodies of water, aquatic activities are becoming increasingly attractive to individuals who find recreation or sports psychologically and physically satisfying. With this increase in aquatic participation, there has also been an increase in the availability of water sports equipment, facilities, and instruction.

The underwater world is still relatively unexplored and filled with a variety of interesting life forms. For this reason, many people are attracted to the depths of the ocean and the beauty it presents.

Man has been interested in the underwater world from as early as 360 B.C. when Aristotle wrote about diving devices (Armbruster, 1979). A more recent and major contribution, which extended the time available underwater, was made by Jacques-Yves Cousteau and Emile Gagnam in 1943, when they introduced the scuba, "self-contained underwater breathing apparatus" regulator (Armbruster, 1979).

Despite the technological advancements in equipment used for aquatic recreation, the rapid growth of participation has far exceeded the regulations designed to make activities like scuba diving safe, yet enjoyable for the recreational diver. The National Underwater Accident Data Center (N.U.A.D.C.) reported that at the end of 1979 there were approximately 2.1 million active divers (McAniff, 1981). An active diver is one who dives at least three times per year. The N.U.A.D.C. also reported for that same year a 10.7 percent increase in underwater diving fatalities for nonoccupational divers (McAniff, 1981). Unless research is conducted to obtain information pertinent to the average recreational diver, then scuba accidents will continue to occur due to the lack of design and implementation of appropriate regulations.

Scuba diving requires a specific level of skill and knowledge that allows individuals the opportunity to participate in the activity. It is one of the few sports which requires special training and certification. It is recognized as an important underwater activity or sport, and scuba instructors must recognize the need for preparing scuba students with the knowledge, skill, and physical fitness required to engage in this activity safely. Instructors and the diving community should be responsible for the support and development of sound public policy and recommendations for divers relating to diver education. The diving community should strive to raise the professional standards, to continually improve diving services, to encourage certified divers to actively pursue diving, and to conduct research which will further the knowledge of diving physiology as it relates to the safety of the recreational diver.

Due to the specificity of training involved in becoming a scuba diver, it would be logical to assume that research has been conducted pertaining to the physiological demands placed on the average sport or recreational diver. Currently there is an abundance of information relating to fit, young, male, highly experienced Navy Divers, and a dearth of information relating to older, less fit, less experienced recreational divers.

Need for the study

Today there exist five major National certification agencies which train and certify divers. Once divers have completed the cognitive and psychomotor requirements for certification, they are then able to dive any time and anywhere they wish for the remainder of their lives.

Issuance of a lifetime scuba certification with a lack of restrictions regarding required renewal or update of basic scuba certification creates a potential risk of injury or fatality to the inactive, less fit, less experienced diver. N.U.A.D.C. (McAniff, 1988) reported that divers with the least amount of experience face a much greater risk of fatality than do divers with considerable experience. Compounding this risk factor is the added risk with aging and decreased physical fitness. In order for expansion and improvement to occur in the potentially dangerous activity of scuba diving, those researchers involved in any aspect of diving must make every effort to continually conduct studies which will provide information on what physiological stresses are encountered by recreational divers diving in various underwater environments. Specifically, the research should be geared towards observing cardiorespiratory and energy expenditure responses to diving in different environments. The results obtained from such research should then be actively disseminated to dive instructors, diving agencies, and recreational divers to increase knowledge, and improve safety. The results should also provide safer guidelines and/or standards, and help to create services for the recreational and sport divers.

If it can be determined that specific diving environments place unusually high physiological stresses on certain populations of recreational divers, then certifying agencies might reevaluate their current certification requirements along with providing more explicit guidelines for diving fitness or experience. This could lead to the first phase in the development of new guidelines for diving safety, and new standards regarding lifetime certification. If and when new guidelines or policies are adopted which would change certified divers' requirements, (such as having them dive on a regular basis, or increase their level of fitness) then the risks to recreational and sport divers' would be reduced, benefiting the entire community.

Statement of Problem

The purpose of this study was to investigate various physiological responses in certified recreational divers while finning at a specific intensity in cold and warm water with and without wet suits. The following physiological measurements were monitored and recorded: 1) breathing frequency, 2) minute ventilation, 3) oxygen consumption, 4) respiratory exchange ratio, 5) heart rate, and 6) core temperature.

Hypotheses

Hypothesis 1

There will be significant differences found between breathing frequency (breaths per minute) during cold versus warm water diving with and without wet suits.

Hypothesis 2

There will be significant differences found between minute ventilation ($\dot{V}_E$, $L \times min^{-1}$) during cold versus warm water diving with and without wet suits.

Hypothesis 3

There will be significant differences found between oxygen consumption (absolute) during cold versus warm water diving with and without wet suits.

Hypothesis 4

There will be significant differences found between oxygen consumption (relative) during cold versus warm water diving with and without wet suits.

Hypothesis 5

There will be significant differences found between respiratory exchange ratios during cold versus warm water diving with and without wet suits.

Hypothesis 6

There will be significant differences found between heart rates during cold versus warm water diving with and without wet suits.

Hypothesis 7

There will be significant differences found between core temperatures during cold versus warm water diving with and without wet suits.

Limitations of the Study

The following conditions were considered to be potential limitations of this study.

1. The variations among the individuals pertaining to adequate rest, activity level, and diet were not completely controlled.

2. The environmental conditions influencing arousal and anxiety were not controlled.

3. Personal or social considerations that may have affected the concentration of the subjects were not controlled.

4. The number of subjects used in the study was relatively small.

5. The workload of 35% max. employed is only an estimate of the workload encountered during recreational diving. It may not represent the work intensity of diving in all diving environments and situations.

6. The coldest water temperature available for the researcher was 18 °C.

7. Only male subjects were tested during this experiment.

Definition of Terms

The following terms have been used in the study and have been defined for clarity.

Buoyancy compensator, (B.C.). A jacket type lifevest used while diving as a means of controlling neutral buoyancy while diving to different depths.

Core temperature. Measurement of rectal core temperature taken in degrees centigrade.

Farmer John wet suit. A neoprene wet suit which consists of a jacket and pant bottoms which are similar to bib overalls. This suit provides double thermal protection over the divers torso.

Heat and cold stress. In order to differentiate between those dives which appear to create an increase in body heat and those that appear to cool the body, the author will refer to dives as either "heat stress" dives or "cold stress" dives.

Neutral buoyancy. The state of maintaining a fixed position where the body neither sinks nor rises without effort while diving.

Normal diving conditions. For the purpose of this study "normal diving conditions" will refer to the two dives which most closely simulate normal cold water diving situations where divers dive with suits, and normal warm water diving situations where divers dive without wet suits.

PCO2. A symbol designating partial pressure of carbon dioxide.

PO2. A symbol designating partial pressure of oxygen.

Regulator. The piece of equipment used by divers which allows them to breathe compressed air from a scuba tank.

Scuba. Scuba is the abbreviation for self contained underwater breathing apparatus.

Scuba tank. A cylindrical metal tank which is filled with normal compressed air and used while diving underwater.

VO_2. Volume of oxygen consumed in liters per minute of time ($L \times min^{-1}$) or milliliters per min per kilogram of body weight ($ml \times min^{-1} \times kg^{-1}$).

CHAPTER TWO

REVIEW OF LITERATURE

Publications relative to scuba diving, exercise, cold versus warm water conditions, heart rate, and oxygen consumption were reviewed. The organizational approach used in reporting relevant findings has been presented in several sections: (a) Physiological Responses (breathing frequency and minute ventilation, exercise and minute ventilation, exercise and oxygen consumption, water exercise and oxygen consumption, measurement of oxygen consumption); (b) Temperature (temperature and water immersion, measurement of body temperature, exercise in the cold, insulation and immersion, temperature and age); (c) Scuba Diving (immersion effects on divers, carbon dioxide retention, heart rate and immersion); and (d) Miscellaneous Factors. The discussion in each section will begin with general background information and progress to publications which are specifically related to this study.

Physiological Responses

Breathing Frequency and Minute Ventilation

The rate and depth of breathing, normally, are finely adjusted in response to the body's metabolic needs. In normal healthy people, the arterial partial pressures of carbon dioxide and oxygen are maintained near the resting value despite large variations in the intensity of exercise. It is known that physical activity (type and intensity) affects oxygen consumption. During rest and exercise, oxygen diffuses from the alveoli into the venous blood returning to the lungs while carbon dioxide moves from the blood into the alveoli. Ventilation ($\dot{V}_E$) increases to maintain the proper alveolar gas concentrations and allow for this increased exchange of O_2 and CO_2 (McArdle, Katch et al., 1986, Åstrand and Rodahl, 1980).

During light and moderate aerobic exercise, ventilation increases linearly with oxygen consumption. At rest and during light exercise the oxygen requirement of breathing is small, averaging 1.9 to 3.1 ml of oxygen per liter of air breathed, or about 2% of the total energy expenditure (McArdle, Katch et al., 1986, Åstrand and Rodhal, 1980). As depth and rate of breathing increase during exercise, the energy expended in breathing increases also. Ventilation will generally be higher during exercises where more muscle mass is involved. Ventilatory adjustment also seems to be very specific to the type of exercise that the subject is accustomed to performing. For example, those subjects who are familiar with underwater finning will tend to adjust $\dot{V}_E$ more readily to underwater scuba tethered finning. The more efficient breathing patterns are generally observed during those exercises for which an individual has trained (McArdle, Katch et al., 1986).

Airway resistance and effects of submergence both add to the respiratory work required to achieve adequate pulmonary ventilation. However, ventilation that would ordinarily be adequate does not always ensure satisfactory exchange of oxygen and carbon dioxide in the lungs. The primary purpose of pulmonary circulation is to allow the blood to take up oxygen from the alveolar gas and to deliver excess CO_2 to the lungs where it can be expired. This requires appropriate matching of alveolar ventilation (VA) and blood flow (perfusion) in the different regions of the lungs. What one wants to see normally is a ratio of $VA/\dot{Q}$ close to 1.0. Gravity and blood within the lungs affects lung tissue. In submergence blood tends to be shifted from the limbs to the thorax. This helps to bring about uniformity of perfusion. At the same time, the external pressure of the water tends to influence the excursions of the diaphragm by reducing the expansion of certain portions of the lungs. This can contribute to $VA/\dot{Q}$ inequality. However, exercise usually improves the uniformity of both ventilation and perfusion. Normally, regulation of ventilation does not cause many problems in divers at rest or during very mild work; but many times divers do perform high intensity exercise in the water.

Exercise and Minute Ventilation

The regulation of breathing during work is still a controversial topic in physiology. Pulmonary ventilation is largely regulated by the chemical state of the blood and cerebrospinal fluid. Variations in arterial PO_2, PCO_2, acidity, and temperature activate sensitive neural units in the medulla and arterial system which in turn adjust ventilation to maintain arterial blood chemistry within narrow limits. However, chemical stimuli will not entirely explain the increased ventilation, or hyperpnea, during physical activity. During exercise, arterial PO_2 is not reduced to an extent that would increase ventilation due to chemoreceptor stimulation. It is known that during easy to moderate exercise, pulmonary ventilation is coupled closely to the metabolic rate in such a way that it is proportional to the carbon dioxide production (McArdle, Katch et al., 1986). Research indicates that increases in body temperature have a direct stimulating effect on the neurons of the respiratory center. Increases in temperature will exert control over ventilation in exercise of long duration (two or more hours) (Whipp, 1979). Although temperature probably exerts some control over ventilation in prolonged exercise, ventilatory adjustments to exercise are augmented by nonchemical regulatory factors. These include: cortical activation in anticipation of exercise; outflow from the motor cortex during exercise; peripheral sensory input from mechanoreceptors in joints and muscles (Åstrand and Rodhal, 1980).

A portion of the air in each breath does not enter the alveoli and therefore is not involved in gaseous exchange with the blood. This air fills the nose, mouth, trachea, and other nondiffusible conduction portions of the respiratory tract. This air remains in what is termed the "anatomic dead space". In healthy people, there are about 150 to 200 ml. of anatomical dead space volume (about 30% of the resting tidal volume). This dead-space air is very much like that of ambient air, but is saturated with water vapor. Because of the dead space, only some of the inspired air (i.e., at rest, 350 ml. of

500 ml.) in the tidal volume enters into and mixes with the existing alveolar air (Åstrand and Rodhal, 1980). This is about one seventh of the total air in the alveoli. This seemingly inefficient alveolar ventilation prevents drastic changes in the composition of alveolar air and assures a consistency in arterial blood gases throughout the entire breathing cycle. The minute ventilation is not always representative of the alveolar ventilation. During shallow breathing, tidal volume is reduced; yet it is still possible to achieve a normal minute ventilation if the breathing rate is increased per minute. If the breathing rate is decreased the tidal volume may increase to achieve a given V_E. During very shallow breathing, tidal volume may not exceed the dead-space air, thus, no alveolar ventilation has taken place. When tidal volume is increased, breathing is deeper and a larger portion of each breath enters into and mixes with the existing alveolar air. It is this alveolar ventilation that determines the gaseous concentrations at the alveolar-capillary membrane. Actually, the anatomic dead space increases (slightly) as tidal volume becomes larger. Anatomic dead space can actually double during deep breathing due to some stretching of the respiratory passages with a fuller inspiration. The increase in dead space is still very small when compared to the increase in tidal volume. Therefore, deeper breathing allows for more effective alveolar ventilation than does similar minute ventilation achieved only through an increase in breathing rate (McArdle, Katch et al., 1986, McArdle, Magel et al., 1976).

Exercise and Oxygen Consumption

Physical activity affects oxygen consumption and the production of carbon dioxide more than any other form of physiological stress. During exercise, alveolar ventilation is maintained through an increase in both the rate and depth of breathing. During moderate exercise, trained athletes achieve adequate alveolar ventilation by increasing tidal volume along with moderate increases in breathing rate. This deeper breathing increases alveolar ventilation from 70% of the minute ventilation at rest, to over 85% of the exercise ventilation. With intense exercise, increases in tidal volume start to plateau and minute ventilation is further increased through an increase in breathing frequency (McArdle, Katch et al., 1986, Sutton and Jones, 1979).

As stated earlier, during moderate submaximal exercise intensity, ventilation increases linearly with oxygen consumption and carbon dioxide production and averages between 20 and 25 liters of air for each liter of oxygen consumed ($\dot{V}_E/\dot{V}O_2$). Consuming one liter of oxygen is equivalent to an energy use of about 5 kilocalories (kcal). Oxygen consumption is designated or expressed as $\dot{V}O_2$ ($L \times min^{-1}$) corrected to standard conditions STPD (Lanphier, 1975).

A person's body size influences $\dot{V}O_2$ during rest and activity. Oxygen consumption values range somewhere between an individual's minimum or basal value and the highest $\dot{V}O_2$ of which their body is capable. Assuming that an individual is relaxed one can expect minimum adult values of VO_2 to be as low as 0.2 L x min^{-1}. However, an "average resting value is about 0.3 L x min^{-1}". Every person has an upper limit that can be achieved during very high intensity workloads involving major muscle groups. With some allowance for body size and "constitutional factors", VO_2 max depends largely on the individual's state of fitness and heredity (Lanphier, 1969).

Oxygen Consumption and Water Exercise

The mode of activity will influence values for VO_2. During prone swimming, the ventilatory equivalents are significantly lower at all levels of energy expenditure. This is probably due to the restrictive nature of swimming on breathing. This restriction may pose a problem in providing for adequate gas exchange during maximal swimming and may partly contribute to the generally lower maximal oxygen uptake observed during swimming compared to running (McArdle, Magel et al., 1976, and Holmer, 1980). Morrison, Haynard et al. (1980) reported a maximum effort during stationary fin swimming against a submerged "trapeze" at various simulated depths. His maximum values closely approximate the mean and range reported by Lanphier (1954) for finning at 1.2 knot with a VO_2 of 1.75 L x min (Lanphier, 1969). Hunt, Reeves, and Beckman (1964) studied actual submerged long-distance ocean swims. They did not measure VO_2 directly, but values between 1.3 and 1.8 L x min^{-1} were derived from other measurements. Speeds were estimated to be between 1.0 and 1.2 miles per hour.

For a scuba diver of average size and fitness a $\dot{V}O_2$ max of about 3.0 L x min^{-1} can be expected (Lanphier, 1969, Hunt, Reeves et al., 1964). Values as high as 6 L x min^{-1} have be reported, but only rarely (Lanphier, 1969). If a diver has a high value for maximum oxygen uptake for his or her size, then he or she has somewhat of an advantage during diving, especially in terms of ventilatory requirements at high work rates because he or she is a more efficient user of oxygen. At the same time, a diver who is poorly fit will be under serious disadvantages in diving if required to work at a high intensity (Lanphier, 1969). Although research has indicated that submergence can affect oxygen consumption, in general it is assumed that submergence and pressure produce no basic change in the oxygen requirements as associated with a given physiological workload (Lanphier, 1969). Instead attention should be focused on ways in which the environment or factors such as the divers breathing apparatus and gas density, affects the divers ability to meet his or her respiratory needs (Lanphier, 1969).

Most studies report an increase in $\dot{V}O_2$ max during swimming in cold water (Pendergast, DiPrampero et al., 1977, McArldle, Magel et al., 1976). The level of max $\dot{V}O_2$ increase appears to be about 10-30% for a decrease in core temperature of 0.5-2.0 °C. In another study, Pendergast (1988) found no difference in max $\dot{V}O_2$ in different water temperatures. However, this study was conducted at higher water temperatures for shorter periods of time; hence the subjects did not have as large a decrease in core temperature as in the studies showing decreased VO_2 max in cold water. Therefore, it is evident that subjects with lowered core temperatures have an increased cost of exercise and increased VO_2 max. Therefore, one would expect the VO_2 values for a specific workload or exercise intensity to be higher during cold water verses warm water exposure. These and other studies (Climsit & Flook, 1981; Craig & Dvorak, 1969) appear to leave little doubt that cooling of the body increases the need for oxygen during exercise.

Generally most studies (Craig & Dvorak, 1969, and 1976) have found that the difference in absolute VO_2 values between cold and warm water is greater during exercise than the difference in absolute VO_2 values observed at rest. Oxygen consumption increases with a decrease in body temperature. This suggests that the net mechanical efficiency of exercise in cold water is lower than would be found under normal conditions.

Measurement of Oxygen Consumption

The underwater environment introduces problems in collecting expired air at depth and accurately measuring oxygen consumption. Generally, during land experiments, researchers use inspiratory and expiratory air hoses which are in line with a one-way breathing valve. The subject breathes in room air and exhales the expired air into the one-way valve. The expired air is collected and measured to obtain information on oxygen consumption, carbon dioxide production, minute ventilation, and breathing rate.

This "open circuit" system is based on the volume of gas respired per unit of time and on the differences in oxygen and carbon dioxide concentrations between inspired and expired gas. During underwater testing "these differences are reduced in proportion to the absolute pressure" (Lanphier, 1969), which requires very "accurate gas analysis if accurate results are expected in studies conducted under high pressure with analysis of gas samples at normal pressure". Using "carefully calibrated electrode type analyzers at the pressure of the experiment is potentially more precise" (Lanphier, 1969).

The usual apparatus for "closed circuit" determination of $\dot{V}O_2$ is not used much underwater because it entails the use of pure oxygen, but some researchers have described other applicable methods used in the determination of $\dot{V}O_2$ that utilize some of the same principles as that of open circuit spirometry, however, these will not be discussed (Lanphier, 1976). Although pure oxygen is used sometimes it is dangerous if determinations are made at depths near or greater than 2 ATA (32-34 feet). Use of other gases besides pure oxygen in a closed circuit system involves risk of hypoxia, requires special precautions, and is expensive. The change in volume, on which the usual closed circuit determination is based, is reduced in proportion to the absolute pressure which compromises the accuracy of determinations (gas analysis) at depth.

Temperature

Beckman (1963) points out that much research has been done in the field of thermal protection during cold air exposure, but very little research has been carried out dealing with immersion in cold water. There are large differences in the physiological effects of cold air versus cold water exposure at the same temperature (Beckman, 1963).

Water has a specific heat of about 1000 times greater than air so each cubic centimeter of water adjacent to the skin can dissipate a thousand times more heat from the body than a comparable amount of air for a given temperature increase. Also, thermal conductivity of water is 25 times greater than that of air. Hence, while submerged in water, body heat is conducted much more quickly away from the skin into the adjacent water layer. Since body heat loss is so rapid in water, the loss is limited mainly by the rate at which heat is transferred by the blood from the central core of the body to the skin. The rate of heat loss is very important to those individuals who stay immersed in water for long periods of time such as long distance swimmers, scuba divers, and hard hat divers.

Temperature Measurement

Beckman (1963) conducted studies on immersion in water at temperatures from 35 °C to 10 °C and with air temperatures from 20 °C to 23 °C (relative humidity from 40 to 55%). The subjects' respiratory minute ventilation ($\dot{V}_E$) ranged from a low in warm water of

400 liters/hr. to a high in cold water of 3000 liters/hr. The heat loss generated from the subjects varied from 65 to 600 kcal/hr. as determined by oxygen consumption. The largest amount of heat lost is due to Newtonian cooling, or the conduction of heat from the body to the water.

Beckman (1963) presents results from Hardy's (1961) study which suggests that the values of thermal conductivity for men are 6-9 kcal/hr./sq.m./°C and 5-8 kcal/hr./sq.m./°C for women. These values are representative of measurements in a body calorimeter and in air, however, they were not obtained during extreme rates of heat exchange.

Beckman's (1963) own research and results on thermal conductivity agree with other results (Hardy, 1961) where subjects were submerged to neck level in water temperatures from 10-34 °C. Hardy (1961) found a 15 fold variation in body insulation among subjects. If this 15 fold variation found in effective body insulation is accurate, it might suggest why a fatter person is better able to tolerate cold.

Research (Keatinge and Evan, 1961) demonstrated a linear relationship between the amount of body heat loss and the reciprocal of skin fold thickness. The values for external or shell tissue insulation have all been obtained by an inference to oxygen consumption. This value was then "equated with equivalent heat generation" (Keatinge and Evan, 1961). Generally, a portion of the total heat loss is assumed to be due to pulmonary evaporative loss, while the remainder is lost by conduction. The data suggests that adipose tissue acts as an insulation along with the underlying layer of muscle to conserve body heat.

The main avenue of heat transfer from the body surface to the surrounding water is convection and conduction (Boutelier, Bouges et al., 1977) because of the long-wave infrared radiation of the body surface. Since water absorbs heat so effectively, radiation transfer is very small. The combined heat transfer coefficient for convection and conduction varies from 44 W (m^2 hr. °C or 38 kcal/m^2 hr °C) in still water to an average of 64 W (m^2 hr. °C, or 55 kcal/m^2 hr °C) in stirred water. Shivering in still water raises the heat transfer coefficient from 44 to 50 (W/m^2 °C) (Boutelier, Bouges et al., 1977). According to the analysis by Rapp (1970), the conductive heat transfer coefficient is about 11 (W/m^2 °C) regardless of the degree of stirring, while the convective heat transfer coefficient increases from 94 (W/m^2 °C) in still water to 400 (W/m^2 °C) at a swimming speed of 0.5 m/sec. These values may be compared with the 1 to 2 (W/m^2 °C) observed at 1 ATA air (26.5 °C) by the U.S. Navy group (Beckman, 1963). Despite such a marked difference in the convective heat transfer coefficient between air and water, heat loss to water has been estimated to be only about two to five times that in air at the same temperature. This indicates that heat loss in water is largely limited by the body (core-to-skin) tissue insulation and not by the skin-to-water heat transfer coefficient. Although the thermal comfort zone for a resting unclothed man immersed in water varies inversely with the subcutaneous fat thickness of the subject, it is reported to be 33-35 °C (Craig &

Dvorak, 1968). Moreover, the critical water temperature, i.e., the lowest end of the zone of vasomotor regulation at which maximal peripheral vasoconstriction develops, is also as high as 29-33 °C, depending upon subcutaneous fat thickness. Since the water temperature most often involved in diving is much lower than this range, "it is obvious that divers are exposed to considerable cold water stress" (Craig and Dvorak, 1968).

Measurement of Body Temperature

Mean skin temperatures in air are obtained by a mathematical weighting system which has been adjusted to fit experimental data. However, when experiments are done in water it has been assumed that skin temperature equals water temperature; but this assumption is wrong, especially if the subject is wearing protective clothing such as a wet suit.

Taking deep body temperature measurements is a more accurate and reliable means of determining temperature than relying on skin temperatures which vary greatly from different body parts. Underwater there is no skin evaporative heat loss, but there is evaporative heat loss from the alveolar lung surfaces, the heat loss used to warm the inspired air to body temperatures, and the heat required to increase the water vapor content of the air up to 100% (Beckman, 1963). This amount of heat is then lost on expiration. It has been estimated that this amount is approximately 15-24% of the total body heat generated, with the loss due to water vapor being proportional to minute ventilation (Beckman, 1963).

Core temperatures have been accurately followed by use of radio--pill or use of external auditory canal thermal probes. Radio-pills are somewhat impractical because of their cost, while the use of ear probes sometimes depend on diver acceptance and the development of a nonconclusive way to hold the probe steady in the external canal. Rectal probes are even less acceptable to divers and the delay found between body core and rectal temperature (this delay can be around five minutes or more depending on the thermal stress) is well documented (Beckman, 1963). Researchers are still waiting for the development of a mathematical model which would allow for prediction of thermal stress and for better methods for monitoring temperature. At this time much of the research has been done by the Yellow Spring Institute (Yellow Springs, Ohio) which is supported by the Office of Naval Research. The institute is working on a device which would heat an area of skin until negative heat flux is attained. Then the gradient established by the temperature should be proportional to the underlying core temperature. To date though, Y.S.I. has supported the use of rectal temperature probes during diving research versus the other available means of temperature measurement.

It should be noted that heat loss from the head is often neglected in the literature. Generally, skin thermal conductivity calculations are calculated as a mean value which implies that conductivity from tissue is fairly uniform. However, heat loss from the head differs from that of the "mean" body insulation. Froese and Burton (1957) obtained data on heat loss from the head in air temperatures from 32 °C to 6 °C. Although data is lacking on heat loss from the head while submerged, some experiments in Dachau (1946-1949) suggest that the head is the most important part of the body in protection against cold water (Beckman, 1963). Results from some of Beckman's experiments supported those obtained from Dachau, and implied that submersion of the head and neck induces a significantly greater heat loss.

One point to keep in mind, is that the average or mean values of heat loss which are calculated, are representative only of the body's plane surfaces, and do not take into account the areas of the body where insulation is anatomically poor, such as hands, feet, ears and nose. Because of the geometry of appendages, the rate of heat loss is great; thus, these areas generally limit exposure tolerance to cold environments even when skin and core temperatures are well within the comfort zone.

Exercise in the Cold

In very cold environments, it is known that the energy expenditure increases which occur during exercise, depend mostly on a person's percent body fat as well as on what type of protective clothing is being worn. Studies have shown that in cold environments little or no change occurs in resting energy metabolism in obese people, while lean subjects exposed to the same environment triple their energy output by shivering in response to the cold stress (Nadel, Holmer et al., 1973). Shivering is a normal response in lean individuals and represents the body's attempt to maintain a stable core temperature in the face of cold stress (McArdle, Katch et al., 1986, and Nadel, Holmer et al., 1973).

The effect that temperature has on resting metabolism is also carried over to cold environment exercise, especially in cold water. "If the water temperature is reduced to 18 °C, the energy cost of exercise becomes substantially increased" (Hemingway, 1963). The increase is due in large part to the amount of energy required to sustain shivering as the body tries to defend itself against the heat loss to the surrounding environment. The insulation benefits of body fat influence the responses to cold water. When immersed in cold water, lean people are at a great disadvantage when compared to individuals with higher percentages of fat. Those with higher percentages of fat are under considerably less physiological (cardiovascular) strain than leaner individuals (Hemingway, 1963).

Shephard (1985) reviewed the various adaptations to exercise in the cold that an athlete encounters. The athlete has a variety of means for sustaining body temperature while exercising in extreme cold: a) voluntary activity; b) shivering; c) non-shivering thermogenesis.

Sedentary young men are capable of maximum aerobic energy expenditures of about 60 KJ/minute, while highly fit individuals are capable of about twice that. During short term high intensity exercise, about 75% of one's total energy output is in the form of heat; however, about only 1/3 of that total energy output can be sustained "during extended sports and exercise such as hill-walking" (Shephard, 1977). Highly fit individuals are thus capable of staying warmer in harsh climatic conditions if exercising at a high intensity. In contrast, a less trained individual exposed to the same environment will quickly become hypothermic (Shephard, 1985).

Shivering results when an individual cannot exercise hard enough to keep warm; however, this thermal protection is very limited. While studies on dogs (Webster, 1974) "have shown a ten-fold increase in metabolism during acute bouts of shivering, the peak effect in humans is probably a five-fold rise in resting energy expenditure". At most, man is capable of a five-fold increase in resting energy expenditure to about 21 KJ/minute for short periods of cold exposure (Pugh and Edholm, 1955, and Nadel, Holmer et al., 1974) and 10-15 KJ/ minute during longer periods (Houdas and Ring, 1982). Although shivering is helpful in increasing metabolism, it greatly decreases coordination of motor skills, which would be a disadvantage while scuba diving.

Non-shivering thermogenesis can arise in either brown or white adipose tissue. The brown adipose tissue generates heat by the action of free fatty acids in uncoupling mitochondrial electron transport and by noradrenaline-induced membrane depolarization and sodium pumping (Shephard, 1985). The existence of brown fatty tissue in the adult human is somewhat of a controversy, and though there are mechanisms (theoretical) of heat production in white fat, the contribution to maintenance of body temperature by white fat is minimal. Non-shivering thermogenesis has been postulated as another means of maintaining core temperature (Shephard, 1985). The main point of controversy is over whether brown fat exists because this is where the non-shivering thermogenesis is supposed to occur. In newborn children, brown fat is very apparent, yet, as stated above, it is much less obvious in adults. It has been suggested that brown fat tends to hypertrophy with outdoor winter exercise (Shephard, 1985).

Humans tend to acclimatize to cold environments by responding with a hypothermic insulating type of mechanism rather than with humorally-mediated brown fat hypertrophy. Although the hypothermic response tends to spare glycogen reserves, it can also hinder manual dexterity (Shephard, 1985).

In a study conducted on subjects submerged in 19 °C water wearing only bathing suits (Johnson, Hayward et al., 1977), it was observed that the sympathetic nervous system responded very fast to cold. After two minutes of immersion in 10 °C water, the researchers found that plasma norepinephrine doubled, and then gradually increased as metabolism increased during the 60 minutes of immersion. After rewarming for 10 minutes in 40 °C, they observed an abrupt fall in norepinephrine and a cessation in shivering. Shivering usually stops when rewarming begins as a result of the rise in skin temperature, even when core temperature remains much below the temperature observed prior to shivering.

Generally, exercise seems to inhibit shivering, but the metabolic response to cold exposure adds to the metabolic cost of the exercise (Webb, 1978). Subjects swimming at an intensity requiring an oxygen consumption between 1.4 and 2.0 L x min^{-1}, showed that cold water from 14 to 20 °C causes an increase in metabolism higher than that needed for swimming as an inverse function of skin temperature. Researchers also noted that during the rewarming period (in air) while cycling, shivering stopped as skin temperature increased despite a low core temperature (Webb, 1978).

Although thermal considerations in air are important for those who exercise on land, scuba divers have to be concerned with thermal conditions in water. Craig and Dvorak (1968) studied the thermal regulation of ten men while exercising (head out) submerged in different water temperatures ranging from 24 °C to 35 °C. The ten men had an average estimated body percent fat of 14%. They wore swim trunks and tennis shoes during the hour long exercise bouts on bicycle ergometers in the water. Two experiments were performed, one with a light workload and one with a heavy load. During recovery (20 minutes) half of the subjects remained in the water, while the other half were raised out of the water and dried. Oxygen consumption, central (ear and rectal) and peripheral (2 covered skin sites: finger, abdomen) temperatures, and heart rates were all observed and recorded.

During the workloads, the subjects averaged 0.70 L x min^{-1} (light) and 0.92 L x min^{-1} (heavier) $\dot{V}O_2$. The changes in ear temperature suggested that the increased heat production during exercise buffered the cooling of water immersion. The rectal temperatures during the light work load were similar to those observed in resting subjects, while the heavy workload elicited smaller decreases in rectal temperatures. Observation of the range of temperatures encountered in this study revealed an indirect linear relationship between ear temperature changes and water temperature. The heart rate was found to be lower in subjects in cool water than in warm water. These observations suggest that (within the water temperature range used) the rise in heat production elicited by exercise is a more effective means of preventing a decrease in heat store than shivering and vasoconstriction which generally provide some thermal protection for the subject (Craig and Dvorak, 1968).

Costil, Cahill, and Eddy (1967) conducted a study in which they observed the metabolic responses to submaximal exercise at three water temperatures. Eight young men with normal body fat percentages swam breaststroke for 20 minutes at a self selected submaximal workload which was regulated by a swimming ergometer. The water temperatures were 17.4 °C, 26.8 °C, and 33.1 °C. Respiratory values, heart rates, and body temperatures were recorded during exercise and recovery periods. Prior to exercise subjects inserted a rectal thermometer and were fitted with thermocouples on the arm, back, and thigh. Direct leads from an electrocardiogram were affixed to the subject's chest. A telethermometer (Y.S.I. model 46 TVc) was used to measure skin, rectal, and water temperatures.

Although the swimmers ventilated more air in the two temperature extremes when compared to the 26.0 °C they did not elicit statistically significant different ventilatory values when comparing any of the three water temperatures. Six of the eight subjects inspired much greater amounts of air in the coldest temperature, while the other two did so in the warmest temperature. The volume of oxygen consumed ($\dot{V}O_2$) per minute and the carbon dioxide produced per minute ($\dot{V}CO_2$) was not significantly different between the three water temperatures. The authors suggest that this data indicates a similar energy requirement at all three temperatures. Respiratory rates were not found to be statistically different in any of the three temperatures, even though subjects respired more often in the coldest water temperature.

During exercise, the mean heart rates did not differ significantly at any of the three temperatures. During the early part of recovery, the lowest heart rates noted were those following exercise in the coldest water. Warm water exercise produced significantly higher recovery heart rates ($P < 0.05$) (Costil, Cahill et al., 1976).

The water temperature during and following exercise affected the subject's skin and rectal temperature. Although skin temperature always remained higher than the water temperature, it was observed that the thermal differential was inversely related to water temperature. Hence the largest difference found between skin and water temperature was in the coldest water and the smallest in the warm water. During exercise the mean rectal temperature increased the most in the 33.1 °C water temperature and the least in the 17.4 °C water temperature. The rectal temperature after exercise (17.4 °C) resulted in a post recovery temperature of 0.25 °C lower than that noted before exercise (not significant). Heat loss in 26.8 °C and 33.1 °C was inhibited during the recovery phase. The authors concluded that the varied water temperatures used in this study did not significantly affect the metabolic responses of subjects during submaximal work.

Dulac, Quirion et al. (1987) investigated the metabolic and hormonal responses to long distance swimming in cold water. The sixteen males and six females swam 32 km. in water temperature of 18.5 °C with mean performance times of eight hours and 32 minutes (men) and nine hours and one minute (women). Subjects were given no dietary restrictions prior to or during the race. Blood samples were taken (fasting state) the week prior to the swim and within 30 minutes after the swim. The mean body percent fat was 13.6% (men) and 24.5% (women) both of which were higher than shorter distance swimmers and marathon runners. Those subjects with a body percent fat of less than 10% did not complete the swim due to hypothermia. Mean rectal temperatures were 35.5 °C for men and 36 °C for women following competition. A positive correlation between body percent fat and rectal temperature was obtained following competition (Dulac, Quirion et al., 1987).

Although somewhat unrelated to this author's research, it should be noted that Dulac, Quirion et al. (1987) also found an increase in plasma epinephrine, norepinephrine, cortisol, thyroxine, free fatty acids, lactate, a decrease in insulin, glucose, and no change in growth hormone, triglycerides, triiodothyronine, and cholesterol concentrations. The authors concluded that similar hormonal responses were obtained from both male and female swimmers. They also suggested that long-distance cold water swimming may represent for some swimmers the limit of cold and long duration exercise tolerance.

Research (Shephard, 1985, and Shilling, Carlston et al., 1984) indicates that individuals submitted to intermittent cold exposure over time (acclimatization) complain less of cold and elicit a lower sympathetic response with "a decreased output of catecholamine" (Shephard, 1985). Shephard suggests that this research has obvious implications for improving an individual's physical performance in cold environments, especially in people who are reaching the "coronary prone" years.

As is known, exercise helps by increasing heat production and should then slow the rate at which body temperature falls during water immersion. These benefits of exercise, though, disappear when in cold water. Research conducted by Pugh and Edholm (1955) on men in water at 16 °C, provided information which showed that the fatter of two men maintained his rectal temperature while swimming, while the thinner man suffered a larger decrease in core temperature when he swam than when he kept still. This suggests that the exercise had an adverse effect on temperature maintenance in the thinner man. This occurred because of the increased movement of the water surrounding the subject, causing an increase in convection and conduction of heat away from the body to the surrounding water.

Research by Keatinge and Evan (1961) showed that exercise helped to slow the normal progression of rectal temperature decrease in both 5 °C and 15 °C water, had no significant effect in 25 °C water, and increased rectal temperature in 35 °C. Keatinge and Evan found that exercise increased heat production in 15 °C water less than in the 5 °C water. This indicated that exercise increased heat loss much more at the low than at the high water temperatures. Keatinge and Evan (1961) stated that "to a first approximation exercise can be assumed to have increased muscle blood flow, and therefore to have increased whole body conductance, by a comparable amount at all water temperatures." If we assume this, then one might expect a much greater increase in heat loss in cold water versus warm water due to the temperature gradient increases as the water temperature decreases.

In other experiments, Keatinge (1960) observed that divers working in cold water were better able to maintain body temperature if they worked very hard than if they worked at a moderate standard rate. Keatinge also observed that the magnitude of the fall in rectal temperature during the first ten minutes of cold immersion was always small and not significantly increased by exercising. He did find that the adverse effect of exercise was increased in studies that were conducted for longer than twenty minutes.

Core temperature represents the balance between heat loss and heat production. Since it is known the rate of heat loss in cold water is inversely proportional to the subcutaneous fat thickness, it is interesting to observe how exercise in cold water affects fatter men. As one would guess, fat men are better able to maintain rectal temperatures, even in 5 °C water. However, exercise always increased the rate at which body temperature fell (in cold water) no matter what the body percent fat was (Keatinge, 1960).

It should be noted that the effects that cold water has on circulation are much more dangerous to divers with cardiovascular disease, coronary artery disease, and hypertension. It appears that cold can cause angina by increasing the work and the oxygen requirement of a heart with narrowed arteries which can't supply the extra blood to meet these requirements.

Insulation and Immersion

Recently, the amount of heat lost during immersion has been obtained by using direct calorimetry. In water of 24 °C for one hour the greatest heat loss occurred in the first ten minutes and required 84 kcal for that ten minutes (Shilling, Carlston et al., 1984). The total loss from body stores of heat during that hour amounted to 183 kcal, 60% of which was lost in the first twenty minutes of immersion. The overall heat loss during one hour of immersion amounted to 275 kcal. Webb (1978) studied three divers who wore lightweight dry suits and swam underwater in temperatures of 5 °C, 19 °C, and 25 °C until they reached their limit to cold tolerance. The subjects averaged a loss of 210 kcal of body heat, with a decrease of 0.3 °C to 1.1 °C in rectal temperature. Webb conducted another study in 1976 where he obtained with direct calorimetry, a heat loss of 292 kcal/hr in one subject during immersion in water of 5 °C. These results suggest that a diver can voluntarily tolerate a body heat loss of about 300 kcal/hr.

During mild water temperatures above 24 °C it is possible to maintain thermal equilibrium by increasing heat production by exercising. Earlier Shilling, Carlston et al. (1984) established that thermoneutral water temperature ranges between 33 °C and 35 °C in a resting subject. The tolerance decreases to 32 °C when a subject is performing continuous work underwater that doubles oxygen consumption, and can even decrease to 26 °C when continuous work triples oxygen consumption (Shilling, Carlston et al., 1984).

Any further decrease in water temperature below 24 °C causes heat loss to become so great that it is no longer possible to maintain thermal balance without wearing a wet suit. Craig and Dvorak (1968) studied the thermal protective effects of wearing a full wet suit during immersion in 24 °C water. Subjects without wet suits produced 90 kcal of heat during one hour of immersion, while they lost a total of 315 kcal, and began shivering towards the end of the hour. With the addition of a wet suit, the investigators found that the rate of heat production and heat loss declined by roughly 30%. At the end of one and one-half hours both the cumulative heat production and total heat lost was found to equal that observed at the end of one hour without a wet suit. The most apparent difference found between the two conditions was noted in skin temperature. Without the suit, the mean skin temperature (Tsk) of the immersed body parts decreased very quickly. After one hour the Tsk was only 1.0 °C higher than the water temperature. While wearing the wet suit jacket only, Craig and Dvorak found that the Tsk stayed considerably above the water temperature. These results would be expected because four of the six sites measured were covered by the suit jacket. They also found that the exposed upper and lower legs were 5 °C warmer with a suit jacket than without the suit jacket. As expected, wearing a full wet suit produced Tsk which remained even higher. The core temperature (esophageal Te) in all three cases decreased by the same amount, 0.2 °C with the decrease not occurring until the second hour while wearing the full wet suit. Wearing the jacket only produced a rate of fall in Te that was about half that observed without any protection.

It appears that wearing a wet suit keeps the skin warm and allows the subject to maintain blood flow to the periphery at a much greater rate than without a suit. Thus, the suit seems to maintain a diver's comfort underwater. Since the skin temperature is higher with a wet suit on, the subjects did not shiver even when the core temperature declined during the two hour immersion by the same amount as when the subject was without a suit.

If immersion temperatures are below 19 °C, an increase in heat production or tissue insulation is needed. Human tissue can be damaged if skin temperatures fall below 13 °C (Beckman, 1963). Tissue insulation is achieved by vasoconstriction and is limited, so an increase in heat production by shivering or increased activity is needed. Shivering alone can bring about rises in heat production from

5-7 times basal, while activity or work can raise heat production by as much as ten times basal or higher (Beckman, 1963). The length of time a swimmer or diver can sustain such high energy work though is limited. Trained frogmen have been observed to maintain a heat output of about 200 kcal/sq.m./hr. (Beckman, 1963).

Pugh and Edholm (1955) studied a short thick man and a tall thin man while the subjects swam in cold water, and then compared the subjects energy expenditure responses. Both swimmers had about equal metabolic heat outputs (600 kcal/hr.), but the shorter thicker man's layer of adipose appeared to protect him thermally. His skin and subcutaneous tissue provided him with about double the thermal protection and 1/2 the thermal conductivity, compared with that of the taller, leaner man. Although a thick layer of adipose is advantageous for thermal protection, excess adipose can be a disadvantage for other health (cardiovascular) reasons.

The problem of thermal insulation for divers was one which generated the use of neoprene wet suits. Original investigations of wet suit development were based on a desirable skin temperature of 38 °C, whereas a comfortable skin temperature has been determined to be 34-35 °C. During exercise, the body appears to be able to remain comfortable at skin temperatures slightly lower than 34-35 °C (Beckman, 1963).

A 1/4" wet suit was first designed to provide insulation for an underwater swimmer in 0 °C water who generates 200 kcal/sq.m/hr. to maintain a skin temperature of 15 °C with a normal core temperature for one hour. A 3/16" wet suit was designed to provide the same protection in 10 °C water, while an 1/8 " proved to be effective in 12-13 °C for up to 45 minutes. However, recreational divers very rarely generate 200 kcal/sq.m/hr. while diving. Therefore, they normally would wear the conventional 1/4" wet suit in the 12-13 °C water temperature when diving.

Ideally, a heavy wet suit should permit a diver to maintain skin temperatures between 29-30 °C while swimming in water at about 0 °C (the freezing point of sea water). However, to provide this amount of protection the thickness of the wet suit would have to be about 1/2", in other words, twice that of conventional suits. Even at this thickness the wet suit would not be able to protect the hands and feet adequately. Although a 1/2" suit could be used, divers would find that the suit is too bulky to wear and hinders dexterity.

The suits' effective protection decreases as depth increases due to the compression of the wet suit material. The protection that a wet suit provides might be adequate at the surface or in very shallow water, however, buoyancy and suit insulation are inversely proportional to water pressure (which increases as depth increases). An average weight diver (1/4" wet suit) requires about 28 pounds of weight to maintain neutral buoyancy at the surface. As depth increases, buoyancy and insulation decrease. A 1/4" wet suit at 2 ATM absolute maintains about 65% of it's original thickness.

Hayward, Eckerson and Collis (1977) studied subjects immersed in cold sea water wearing light clothing and life jackets. Although this study was an observation of non-diving subjects (without wet suits), it provides some information on metabolism in different water temperatures. Hayward, Eckerson et al. (1977) described a relationship between metabolic rate and water temperature. At temperatures between 5 and 18 °C, the researchers observed an increase in metabolism four times above resting level at the coldest temperature, but in none of the cases was the increase sufficient to prevent a decrease in rectal temperature. In another study Hayward and co-workers (1977) studied eight men wearing only bathing suits while immersed in 10 °C water. The researchers developed equations with which to predict metabolic rate as a function of skin temperature and core temperature. It should be noted that the subjects were young, thin, men and women immersed head out and the predictions developed have not been tested for people with higher percentages of body fat, or older in age.

Normally divers wear some sort of thermal protection while diving and the cold exposures are not as severe as those seen with nude men in 10 °C water. During diving, shivering is usually a late symptom and it has not been determined whether the shivering response can be predicted on models such as the one proposed by Hayward, Eckerson et al. (1977).

Webb (1978) believes that the rate of cooling, body size, and body fat are all important variables in predicting core temperature change from heat loss. In his research he found that slow cooling over long periods of time can result in large heat losses (300 kcal) while at the same time resulting in very little changes in core or skin temperature and little metabolic response. The same amount of heat lost quickly by direct immersion in cold water would result in a large metabolic response, a rapid decline in skin and rectal temperatures. Webb also noted that the larger subjects had a greater tolerance for a given heat loss and had smaller body temperature changes. Apparently "cooling rates much slower than that experienced by men immersed nude in cold water are realistic in diving operations" (Webb, 1978). While thermal protection of clothing may attenuate short term cold exposure, long, slow cooling may be a more serious problem to divers (Webb, 1978).

Webb (1978) presented results of a study conducted on trained U.S. Navy men during a realistic open water cold exposure. The divers wore the usual multiple layers of neoprene wet suits in water temperature of 6 °C. In the four and six hour trials the men shivered and reported having painfully cold feet and hands. A single skin temperature (medial thigh) dropped continually from 28 to 22 °C in six hours. Rectal temperature decreased 1.2 °C and then stabilized at 36.5 °C. The long, slow cooling was physiologically tolerable, but the men lost a large amount of heat despite the small change in core temperature. This study was conducted on divers who were on a wet submersible in the Puget Sound. As time passed, the pilot of the submersible made errors in keeping correct headings. The second man found it hard to concentrate on his job as sonar operator and had a hard time recalling a "well-known procedure" (Webb, 1978).

Another study observed the performance of divers wearing wet suits in 20 °C and 5 °C. They took five skin temperature measurements along with rectal temperature. Within ten to fifteen minutes in the 5 °C water the men were cold and shivering, two of the fifteen divers could not complete the 40 minute dive because of the cold stress. The divers performed simple math, logical reasoning, work recall, work recognition, and manual dexterity. In the cold all divers showed immediate degradation. The researchers termed this "a distraction effect." Only one test (work recognition) worsened as rectal temperature declined. Webb stated that other studies have shown some performance decrement with cold temperatures. He believes that hypothermia during diving remains a major concern, but "perhaps the right laboratory studies have not yet been designed" to look at the problem (Webb, 1978).

Hoar, Raymond et al. (1976) studied fourteen divers in swim trunks who performed ergometer work while breathing air at three meters in 25.5 °C water. Hoar and his co-workers were looking at the physiological responses of men working in the 25.5 °C water while breathing air or helium tri-mix. They observed that the divers were stressed by the work and the cold water. In normal air, exercise produced increases in heart rate, minute ventilation ($\dot{V}_E$), oxygen consumption ($\dot{V}O_2$), and catecholamine blood levels. Despite the exercise the cold water lowered the rectal temperature and contributed to the increase in $\dot{V}O_2$ and catecholamine blood levels. Immersion, cutaneous vasoconstriction, work, and scuba breathing added to a quick diuresis. The researchers suggested it was due to the centralizing blood volume and thus stimulation of central vascular volume receptors.

A study was conducted which compared the metabolic, thermal, and cardiovascular responses of acclimated and unacclimated Navy Divers (Webb, 1978). To summarize, researchers found that there was a distinct variation in metabolic, thermal, and cardiovascular parameters between cold-water-acclimated and unacclimated divers. The study also showed how the combined effects of cold and pressure severely limit the efficiency and bottom time of divers, especially with increasing pressures (2 ATM to 3 ATM). This was especially true for the unacclimated diver. The increase in oxygen consumption and the large increase in respiratory minute volume would considerably limit bottom time. The researchers felt that the early thermogenic response to cold and pressure, increased intensity of metabolic function and initial tachycardia observed in unacclimated divers exposed to cold and pressure could be used as a tool to evaluate the degree of acclimation.

So far only thermal balance during shallow immersion has been discussed, it has not been discussed with respect to diving at greater depths under much higher pressures, which is the situation that a diver encounters. As stated before, skin heat loss increases very quickly in the water even at moderate temperatures. Even in subtropical Hawaiian water (25 °C) the temperature is considered stressful in terms of thermal balance especially during long dives

(Shilling, Carlston et al., 1984). Because of this, divers should wear some sort of protective suit whether it be a 1/4 " or 1/8" suit to help to minimize heat loss through the skin during prolonged dives or if several dives are made within one day. Keep in mind that the thermal protection of a suit decreases as depth and pressure increase. There are a variety of wet suit thicknesses available along with dry suits and special suits pressurized with helium. However, the typical sport or recreational diver most likely will dive with a thinner suit or no suit at all in very warm tropical waters and a 1/4" suit in colder waters (Shilling, Carlston et al., 1984).

Temperature and Age

One aspect of thermoregulation that has not been considered is the effect of aging on heat loss. Generally, with advancing age there is a decrease in basal oxygen consumption of men and women when calculations are based on body surface area.

Vasomotor and metabolic responses to cold are less in men between the ages of 46-67 years than in younger men (Shilling, Carlston et al., 1984). Evidence also suggests that thermoregulatory mechanisms progressively deteriorate as one ages. Hayward and Keating (1979) found abnormally early increases in oxygen consumption and large decreases in rectal temperatures when older people were exposed to cold, though Keatinge (1960) suggested that these observations could be explained by a smaller percentage of subcutaneous fat found in older men (Beckman, 1963).

In summary, the following should be considered when investigating heat loss and caloric expenditure during scuba diving at depth: the individual diver's body percent fat; wet suit type and thickness; maximal oxygen consumption; swimming intensity; minute ventilation; water temperature; water depth; and age.

Scuba Diving

Scuba diving is an activity which takes place underwater at different depths for prolonged periods of time. In order to stay at depth, a diver must use special breathing equipment which can deliver air to that diver when he or she inhales. Recreational divers use regulators which deliver air at a pressure that is equal to the water pressure which surrounds them. As divers dive deeper the water pressure around them increases thus the air that is delivered to them by the regulator is compressed to the same pressure as that of the surrounding water. In this manner they can continue to dive with no adverse affects.

Using an open or closed circuit self-contained underwater breathing apparatus (scuba) at depth, directly affects the density of the air breathed and results in an increased breathing resistance. This added resistance in turn increases the work of breathing in both the airways and the breathing apparatus (the air that is compressed becomes denser and thus harder to move into and out of the lungs, especially at very deep depths).

Many diving studies are conducted in hyperbaric chambers with some work done underwater. One useful experimental method used in determining the workload of underwater exercise was the drag board designed by Pilamanins, Henriksen et al. (1977). The drag board introduces a reproducible resistance to the swimming diver. Hence a standard exercise protocol can be administered by regulating swimming resistance and speed. Open water measurements are generally difficult to take due to the constraints imposed by the environment. However, Dwyer (1977) used an elaborate system which accurately measured O_2 consumption at different depths and exercise intensities during the same dive. He also developed a system which recorded the electrocardiogram, ventilation, breathing frequency, and tidal volume during open-water diving (Dwyer, 1977).

Immersion Effects on Divers

Shilling, Carlston, et al. (1984) present an abundance of information pertaining to the physiology of diving in their book The Physicians Guide To Diving Physiology. They discuss what different effects immersion has on the diver.

The authors look at the immersion influences on respiratory function. They state that during immersion respiratory functions can be related directly to the pressure effects and also to indirect effects caused by the changes in blood distribution. Much of the research has used subjects (who are in the upright position) immersed only to the neck level. Changes observed in the respiratory system during submersion for the following variables are:

1) Vital capacity (VC) is reduced;
2) Functional residual capacity (FRC) is reduced, primarily as a result of lowered expiratory reserve volume (ERV);
3) Closing volume (CV) and volume of trapped air are increased;
4) Lung compliance (CL) is reduced;
5) Diffusion capacity of the lungs is increased;
6) Distribution of ventilation is shifted towards more ventilation in apical regions and less in basal regions of the lungs;
7) Flow resistance is increased;
8) Strenuous exercise at depth may be associated with increased dyspnea. (Shilling, Carlston et al., 1984).

The changes documented in VC range from 0% to 15%, with an average of 6%. Dahlback and Lundgren (1972) reported that water temperature caused large modifications of VC. In water of 35 °C the VC decrease averaged 5%, while in cooler water of 20 °C the decrease was 10%, indicating peripheral vasoconstriction forcing blood into the thorax. In warmer water (40 °C) no significant changes in VC was indicated, suggesting that a considerable amount of peripheral blood pooling existed.

One notable effect of immersion is that it changes the distribution of pulmonary ventilation. The apical regions that are distended (at FRC) and underventilated in nonimmersion become less distended due to compression during immersion and therefore amenable to larger volume changes with each breath. By contrast, ventilation in basal regions is reduced, presumably mostly because of airway closure. This airway closure can be demonstrated by measurement of trapped air volume (Dahlback and Lundgren, 1972) or closing volume (Bondi, Young et al., 1976).

There are probably several mechanisms behind the airway closure during immersion. With increased blood content the lungs will most likely be heavier, and therefore they tend to compress airways in dependent regions. Furthermore, an erectile effect on the alveolar walls by blood engorged capillaries may reduce the recoil of the lungs. This will increase pleural pressure and therefore pressure on the outside of the airways, increasing the tendency for them to close. The fact that breathing is performed at a lower FRC also reduces the recoil force of the lungs, adding to the closing mechanism just described. Measurements of closing volume or closing capacity during head-out immersion have given somewhat conflicting results (presumably for technical reasons). However, the bulk of the evidence indicates a tendency for increased closing volume during immersion (Bondi, Young et al., 1976, Saltzman, Salzano et al., 1971, Morrison and Butt, 1972). Clearly, when the FRC is low, as in immersion, and closing volume is increased, there is a greater possibility that some airway closure will occur within the span of the tidal volume (toward the end of the expiration).

Lung compliance is reduced during immersion due to the vascular engorgement of the lungs; hence they become stiffer. Dahlback, Lundgren et al. (1972) reported a 30% reduction in static compliance while a 37% decrease in dynamic compliance was found.

As noted earlier, there is a reduction in FRC during immersion. Immersion tends to decrease airway diameter, and has been given as the explanation for an observed increase of about 30% in average pulmonary gas flow resistance during tidal breathing. The increase flow resistance is reflected in a 15% decrease in maximum voluntary ventilation, reported by Flynn, Camporesis et al. (1975).

Each of the variables (increased lung stiffness, gas flow resistance, and hydrostatic pressure on the chest) will result in an increase in respiratory work of about 65%. However, the respiratory work performed is still small (compared to the total work performed) and assumed to be of little importance during resting conditions at 1 ATA. Currently there is a dearth of information pertaining to respiratory work during immersion while exercising.

Kurss, Lundgren et al. (1981) studied the effect of water temperature and vital capacity in head-out immersion. Immersion has been thought to reduce vital capacity (VC). The mechanism for this being due to the hydrostatic effects, which cause intrathoracic blood pooling. Kurss, Lundgren et al. (1981), though, found that during lung volume measurements in immersed subjects there was a tendency for VC to recover during exercise. They thought that a reduction in thoracic blood pooling following warming and vasodilation in peripheral tissues was the possible mechanism that could account for the observed increase in VC. Kurss, Lundgren et al. (1981) tested the influence of different water temperatures on VC in the immersed condition. Their results suggested that when measuring lung volumes during immersion, researchers should consider the thermal situation of the subject. Also, to the extent that intrathoracic blood pooling has secondary effects on cardiorespiratory function (causing air trapping, changes in compliance, and cardiac output) these effects may also be modified by changes in thermal stress. They also observed that exercise during warm water immersion (probably through peripheral vasodilation) almost completely counteracted the hydrostatic effect seen during the neutral temperature immersions. The researchers suggest that this may indicate that in high temperatures the external hydrostatic load incurred during immersion may be overcome by intra-vascular hydrostatic forces.

Since ventilation is a physiological parameter researchers are interested in, the U.S. Navy developed a technique for measuring lung volumes by paired magnetometers which is supposed to provide on-line accuracy for following minute ventilation and other ventilatory parameters (Shilling, Carlston et al., 1984). The Navy is currently working on these monitors with submerged divers. However, monitoring ventilation is still limited to listening to breathing patterns of the diver through voice communication systems (Shilling, Carlston et al., 1984).

As far as monitoring oxygenation, the Navy is still developing a device for "PO_2 sampling in the inspiratory hose, with servofeedback to the oxygen delivery system in deep closed circuit" operations (Shilling, Carlston et al., 1984). This type of on-line sampling is not used in shallow-water diving even though there is known hypoxia-producing effects of immersion, a decrease in functional residual capacity, an increase in air trapping and a mismatching of ventilationperfusion (Shilling, Carlston et al., 1984).

With respect to circulatory function, it has been noted that immersion brought about a marked increase in cardiac output caused mostly by an enlarged stroke volume. The immersion evokes the Starling mechanism, but it appears that the effect on the circulation disappears as the water temperature increases. Rennie et al. (1984) however, obtained cardiac output values during rest and in water below 34 °C and found them to be somewhat lower than those taken during nonimmersion. With exercise, though, the cardiac output approached the levels achieved under dry conditions. Because it is hard to design experiments in which exactly the same exercise is performed under both wet and dry conditions information about circulatory adjustment to exercise during immersion is lacking.

One aspect of immersion that has not been addressed is that of diuresis, which might cause divers to urinate frequently (about 350 ml/hr). During immersion the diver becomes gradually dehydrated, and it is known that dehydration reduces a subject's work time because of exhaustion. It also hinders one's ability to dissipate heat (McArdel, Katch et al., 1986). Even though the problem with heat dissipation might occur, it probably would only affect a diver while he/she were wearing a wet suit while on land prior to entry into the water. Straus and Samson (1986) reported a relationship between individual differences in water balance and morbidity in altitude decompression sickness. Their results should be considered with respect to disturbances in fluid-electrolyte balance which may cause circulatory or other changes that could influence a divers susceptibility to decompression sickness.

One last topic to cover with respect to immersion effects on divers is that of efficiency in the water. Normally, the energy is takes to move in water is very large because of the viscous resistance of the water. The mechanical efficiency of underwater fin swimming has been estimated at roughly twice that of the front crawl (between 6% and 15%, Rennie, 1971). The viscous water resistance hinders quick movements, unlike that found in running or cycling where the mechanical efficiency is 20% to 25%.

Carbon Dioxide Retention

A diver's ability to exercise underwater is adversely affected by factors such as increased air density, cold, decreased efficiency, and CO_2 retention. Brooks and Fahey (1983) suggest that ventilation may be the limiting factor of exercise performance in scuba diving. As depth increases, maximal voluntary ventilation decreases, and this results in a smaller difference between exercise ventilation and maximal voluntary ventilation during heavy exercise. As the diver descends to greater depths the higher density of air breathed increases the flow resistance in the scuba equipment and airways which results in hypoventilation. This then leads to an increase in CO_2 retention, breathing work, and dyspnea. A diver's ability to increase expiratory flow rate is limited and after maximum flow rate is reached any further effort may result in partial collapse of the airways.

Generally a diver performing the same amount of work would take about the same number and size of breaths per minute at 3 ATA (64 feet) as at the surface (1 ATA, Lanphier, 1975). The one abnormality observed during diving is a decrease in VA with a subsequent increase in $PACO_2$ and $PaCO_2$. This results in hypercapnia, or what is called carbon dioxide retention. Some divers tend to be more prone to carbon dioxide retention than others, and the limitation of activity depends largely on the level of $PACO_2$ that the diver will accept (Lanphier, 1975).

Why do some divers fail to breathe adequately when they dive? Those divers that have been tested were healthy and generally in a good state of fitness with a high tolerance to exercise. Schaefer (1969) believes that these divers represent those who have adapted to carbon dioxide and assumes they have had extensive exposure to high levels of carbon dioxide. Much of the research confirms a close relationship between diving experience and CO_2 retention (Lanphier, 1975).

Whatever the cause of CO_2 retention, it seems to be the most important single factor in the problem of abnormal $PACO_2$ and the serious effects that it has on a diver. There are other factors which are important (increased work of breathing at depth, high PAO_2, and excessive apparatus dead space), but their effects seem to be magnified in divers who tend to retain carbon dioxide even under ideal work conditions. Lanphier (1975) suggests that in large diving activities, a standardized test should be administered that would detect and quantify this tendency, and permit surveillance at least in the most extreme cases. Anytime a diver retains carbon dioxide he/she is left more susceptible to decompression sickness.

Since elevation of $PACO_2$ in diving seems almost inevitable, Lanphier (1975) outlines some preventive measures:

1. Keep the work of breathing as low as possible and minimize other causes of impaired ventilation;
2. Avoid carbon dioxide in the inspired air and keep dead space to a minimum;
3. Recognize that some elevation of $PACO_2$ will probably occur and that such carbon dioxide-related hazards as oxygen toxicity and narcosis should be avoided by a wide margin;
4. Avoid unnecessarily heavy exertion;
5. Pay particular attention to carbon-dioxide-retaining divers, keeping in mind that they may develop carbon dioxide intoxication or related difficulties where others may not (Lanphier, 1975).

While dyspnea may occur during heavy exercise, it does not always decrease exercise capacity (Brooks and Fahey, 1983). Dyspnea, however, could prove to be extremely dangerous during heavy exercise in an emergency situation. Any CO_2 retention during heavy work increases the risk of CO_2 intoxication. Much of the research indicates that O_2 consumption increases in submaximal work with increasing depth (Brooks and Fahey, 1983). Oxygen consumption is affected by increasing depth, due to the increased energy cost of breathing, the maintenance of body temperature in the colder water and activity in much higher hydrostatic pressures than found in shallow water. As depth increases, water temperature generally decreases. Although wet suits keep a diver from getting chilled too fast, they lose their ability to provide thermal insulation as depth and pressure increase. The decreased insulation can lead to increased O_2 consumption as the body tries to maintain body temperature. Also the increased hydrostatic pressure increases the viscosity of the surrounding water and may hinder a diver's mobility with or without a wet suit.

Much of the research on divers has been conducted on highly experienced divers, and it is known that such divers can work at as much as 91% of their land-measured maximal O_2 consumption for short periods of time (Brooks and Fahey, 1983). However, a diver's effective work is largely reduced because of the reduced efficiency underwater. Brooks and Fahey state that the most important factors ruling a diver's maximal exercise capacity is the ability to tolerate high CO_2

levels, and the percentage of maximal O_2 consumption that can be reached prior to reaching the critical PCO_2 level.

The energy cost of swimming underwater can also be affected by factors such as the swimming angle and the drag coefficients produced by scuba equipment. As much as a 30% increase in O_2 consumption can be incurred by swimming (30 m/minute) in a partial feet down position as opposed to a horizontal position. Improper adjustment or placement of equipment, or differences in swimming efficiency all can affect O_2 consumption.

Because the differences between exercising on land and underwater are so great, relationships between land-measured O_2 consumption and heart rate response are potentially dangerous and should not be used when dealing with underwater situations (Brooks and Fahey, 1983).

Heart Rate and Immersion

The slowing of the heart rate is one of the most recognized effects that water immersion has on the cardiovascular system. In part, the decreased in H.R. is due to the "diving bradycardia reflex", where face immersion in water causes a slowing of the heart rate (Mukhtar and Patrick, 1984 and Craig, 1963) and in part to cardiovascular changes. Heller (1897) was one of the first to report results of studies made on caisson workers exposed to 2.5 and 3.6 ATA. They found that resting heart rates were decreased by about 15 beats per minute (bpm) during either pressure. Heller and his co-workers also found that the average heart rate increase following work was "decidedly smaller than the average increase of pulse rate of workers under normal atmospheric conditions" (Shilling, Carlston et al., 1984).

Research (Bevegard, Horngren et al., 1963, and Homlgren, Jonsson et al., 1960) revealed that heavy work has elicited a greater cardiac output and a slower H.R. in the supine as compared to the upright position. These difference were due to a larger stroke volume in the supine position.. During submaximal work Hellstrom and Holmgren (1969) found lower heart rates in the supine as compared to the sitting position. These studies suggest that the lower heart rates swimming, in either prone or supine position may be due to a facilitated venous return and greater cardiac filling which would result in a larger stroke volume, increased cardiac output, and a lowered heart rate during submaximal or maximal work.

During water immersion in thermally neutral water there is thought to be a translocation of about 700 ml. of blood to the thorax, which in turn brings about a 30-40% increase in cardiac output ($\dot{Q}$:stroke volume x heart rate). The translocation of the blood to the thorax appears to cause an increase in end diastolic volume which causes an increase in filling time, an increase in cardiac output and results in a decreased heart rate (McArdle, Magel et al., 1978).

During immersion in cold water, the $\dot{Q}$ increases to an even greater extent than that observed in either thermally neutral water or warm water. It has been suggested that the 700 ml of blood translocated to the thoracic area in the thermally neutral water is the maximal pooled volume and hence no further blood pools in that area even when there is vasoconstriction and venoconstriction in cold water. In thermally neutral water, blood pressure remains about the same as that in air, however as water temperature decreases diastolic pressure increases (about 10 torr) Colten and Bell et al., 1971). It is thought that the peripheral vasoconstriction caused by the cold elicits this response. The increase in diastolic pressure suggests an increase in the cardiac afterload, (which then could offset part of the effects of increased cardiac preload). With the increase in afterload, there appears to be an increase in cardiac output and a decrease in heart rate (about 10 beats/min.) in cold water immersion (Colten and Bell et al., 1971). One should note that these expectations of heart rate values are for non-exercising individuals. Therefore, one might expect different heart rate responses in divers who not only are totally submerged, but who are involved in exercise, because much of the literature cited on heart rates in water is related to immersed (head out) and non-exercising subjects. Therefore, comparison between studies can not be made with any accuracy.

Shilling and his colleagues (1984) conducted research which measured heart rate and blood pressure of subjects reclining, standing, and exercising during exposure to air at 2, 4, 6, 7, and 10, ATA (60, 120, 180, 220, and 330 foot depth). Each exposure to increased pressure was preceded by controlled measurements taken in the pressure chamber at normal atmospheric pressure. The results revealed a decrease in heart rate with exposure to pressure, with the average decreases for all pressures to be 9.12 bpm while the subjects were reclining, 11.1 bpm while standing, and 12.1 bpm while exercising. A decrease in blood pressure also occurred with exposure to increased air pressure. Since these early studies, several other researchers have tried to determine what physical factors are responsible for the decrease in heart rate. The areas of investigation have included: increased partial pressure of oxygen; increased gas density; pressure per se; and gas tensions of nitrogen and helium. Research has demonstrated that the increased PO_2 is in part responsible for the slowing of the heart rate when exposed to compressed air. Fagraeus, Hesser et al. (1974) determined that about one third of the decrease in heart rate was brought about by the increased PO_2 while the remaining decrease was caused by some factor(s) related to the increased nitrogen pressure.

Researchers generally use heart rate as the only measure of cardiovascular stability in diving situations. To date, invasive monitoring of cardiac output has never been performed in diving research. Although heart rate is the most commonly measured physiological parameter, its implications have yet to be fully understood. There are numerous reflexes which affect heart rate; of these some are stimulated directly by diving. The measurement of oxygen consumption during water exercise (swimming) for example can cause an increase in pulse as high at 215 bpm at $\dot{V}O_2$ levels of 4 liters x min^{-1} (Åstrand and Rodahl, 1977). "Superimposed upon this increase is the bradycardia known to occur with hyperoxia, increased pressure, gas density" (Flynn, Camporesis et al., 1975), "and apnea caused by immersion in cold water " (Shilling, Carlston et al., 1984). In other words what would heart rate values be if the known bradycardia responses were not in effect? Lastly, consideration must be made of the endocrine and autonomic control of the heart rate, where catecholamines, and core temperature provide for a very individualized heart rate at different exercise intensities.

Heart rate can be monitored in a variety of ways, one of which uses the application of superficial electrodes and electrode gel, which is sealed with collodion, taped in place, and held in place by the wet suit. This can provide the researchers with an on-line readout of heart rate. Shilling, Carlston et al. (1984) suggested that three electrodes be used to provide greater reliability and to decrease 60-Hz noise. What appears to be of most importance in monitoring heart rate is to monitor the trend of an individual's heart rate versus trying to establish absolute end points for maximum heart rate. Other software used to monitor cardiovascular function in the diver beyond that of heart rate is not yet available (Shilling, Carlston et al., 1984). To date there are a few underwater heart rate monitors available, most are still in the initial design phases. These systems consist of a wrist watch which records and provides a digital read out of the heart rate, and of a chest strap electrode system which monitors the heart rate.

Miscellaneous Factors

The following text provides brief summaries of miscellaneous factors which are not directly related to this author's research. However, the following factors are presented here to allow the reader to gain a comprehensive understanding of what variables play a role in diving safety.

Dietary factors

Another consideration while diving is that of dietary effects. Divers should eat a well-balanced diet consisting of carbohydrates, fats, proteins, minerals, and vitamins. In the past, most diving experiments did not regulate or enforce specific dietary requirements. The divers were allowed to eat whatever they wanted and either no records were kept or the records were very poorly kept. Generally, for short dives which do not require decompression, dietary regulation may not be a major concern, however, it is the compounding of problems which ultimately leads to diving fatalities. In general a two hour lapse should exist between the last meal and a dive because lipemia may lead to thrombi and blockage of the circulation. Consuming a diet high in carbohydrates, low in fat and low in protein prior to diving is desirable (Shilling, Carlston et al., 1984).

Fatigue/Workload/Mental & Physical State of Divers

There are several factors which might increase an otherwise healthy diver's susceptibility to a diving fatality. One problem encountered during diving is the loss of consciousness which might be brought about by certain environmental or physiological situations such as the following:

1) Low Blood Sugar. Hypoglycemia can result from fasting or very hard work.

2) Fatigue. Extreme fatigue may occur as a result of either hard work and/or loss of sleep.

3) Hypothermia. Consciousness is clouded as body temperature approaches 4 °C below normal (33 °C) and is lost about 6 °C below normal (31 °C). Cold stress dives may not only cause hypothermia but they can increase a divers susceptibility to decompression sickness.

4) Overheating. A diver can become overheated when working in water at or near body temperature. This can lead to heat exhaustion and increase the diver's vulnerability to other factors including decompression sickness.

5) Dehydration. Dehydration would normally result from inadequate fluid intake, and could increase the risk of decompression sickness.

6) Emotional States. A diver who is preoccupied or afraid may be at risk. This is probably a much more important factor than is generally realized.

7) Inexperience. Surveys have shown that the inexperienced diver has a greater chance of being involved in an episode of loss of consciousness while diving (Shilling, Carlston et al., 1984).

8) Carbon dioxide retention. Retention of CO_2 can result from exercise that is excessive for the breathing system in use, especially where the gas is dense. The increased level of CO_2 will lead to increased breathing rate, headache, nausea, and may cause convulsions just prior to loss of consciousness. Even though it would take a high level of carbon dioxide to cause loss of consciousness, it should be noted that some individuals are more susceptible to this than others.

9) Hyperventilation. If ventilation is very large, then CO_2 is eliminated faster than the body produces it, lowering the CO_2 level in the blood. As the CO_2 level in the blood is lowered to less than half the normal level, constriction of blood vessels in the brain occurs, and causes dizziness and other symptoms similar to those of hypoxia. Hyperventilation can sometimes lead to muscle spasm and possibly unconsciousness. Divers who feel anxiety can increase their breathing frequency and begin to hyperventilate, thus increasing anxiety

because they may feel they are not receiving enough air from the regulator. This, of course, only compounds the problem (Shilling, Carlston et al., 1984).

Age

Although chronological age does not necessarily indicate an individual's development, strength, maturity, or intelligence, for the purpose of setting standards, the training agencies will not train people younger than fourteen years, and those who are fourteen can dive only if they are partners with a responsible family adult eighteen years or older. Minimum age for normal certification is fifteen years. On the other end of the scale there is no older age limit for diving. Attention should be given to the neuromuscular, pulmonary, and cardiovascular condition of older divers whether they are engaged in commercial or sport diving. As one ages, susceptibility to particular diving problems is increased (decompression sickness). What appears to be of importance is not a diver's chronological age but physiological age since diving requires coordination, strength, and endurance (Shilling, Carlston et al., 1984).

Body Composition

Having a high percentage of body fat to lean muscle presents a problem not only to the average person, but especially to the scuba diver because of the effect of inert gas exchange and its relationship to decompression sickness. It is also a reflection of the diver's general physical fitness level. Shilling, Carlston et al. (1984) suggests that being more than 20% over ideal weight (with body build and age considered) should disqualify commercial, scientific, and military divers. Sport divers should be discouraged from diving until they fall within acceptable levels; but to date there are no means with which to enforce such regulations, nor are there any standard acceptable levels prescribed for body percent fat.

Stress/Training

Diving has become so popular in the past decade, that diving has evolved from the early stages where strong watermanship was required, to the current philosophy where minimal watermanship skills are needed. The training (currently required) now enables individuals to dive within their own limitations rather than to meet rigorous performance standards. Many believe that the development of new equipment has made diving easier and placed more of the emphasis on reliance upon equipment versus reliance on physical fitness or water skills (Egstrom, 1982). Unlike other countries which require more rigorous, and continual training experiences, once divers in the U. S. are certified they are not required to maintain learned skills, maintain fitness, or continue training. Shilling, Carlston et al. (1984) believes this to be "an inadequacy in our training programs and a serious source of potential danger to divers under stress" .

Not only can a diver be mentally stressed during diving, but a contributing physiological stress can act as an additional stress. The underwater environment, cold, currents, pressure, equipment drag, and exercise all lead to one main stressor: fatigue. Therefore, the less fit diver will most likely encounter more problems than the more fit diver.

The water environment hinders movement, decreases efficiency, and creates additional drag as equipment is added to the diver. The addition of equipment to the diver continues to increase drag starting with the basic equipment (wet suit, mask, fins, tank, weight belt, buoyancy compensator), and continues to increase as extra equipment is added (goodie bag, spear gun, extra tanks, camera, knife). As drag increases so does the work performed by the diver (Shilling, Carlston et al., 1984).

Exercise can be thought of as a function of several factors: physical condition; the environment within which it is performed; the nature of the environment with respect to cold (which further stresses the diver); and the equipment which helps in one respect by aiding the diver but hinders in another by taxing the diver's strength and endurance. Each of these variables adds to the fatigue of the diver. The level of fatigue and the time of onset is different in the water environment than it is on land. On land a person can stop to rest if he or she is fatigued while underwater it is much more difficult to do so. The energy expended coupled with such factors as cold and progressive hypothermia as the dive continues will greatly contribute to the overall stress on the diver (Shilling, Carlston et al., 1984).

Acclimated Versus Unacclimated Divers

There is evidence that there are distinct variations in metabolic, thermal and cardiovascular parameters between cold-water-acclimated and unacclimated divers. Studies were conducted (Clingman and Evonok, 1978) which compared metabolic, thermal, and cardiovascular responses of acclimated and unacclimated Navy divers. These studies have shown that heat loss at 2 ATA is about the same for acclimated and unacclimated divers, while at 3 ATA the heat loss for the unacclimated subject was greater than the acclimated subject. This difference found was attributed to the much greater increase in heat production by the unacclimated subjects. Unacclimated divers also had much higher oxygen consumption rates than the acclimated divers. The unacclimated divers increased their heat production, for the most part, by moderate to violent shivering in submersion and under pressure (Clingman and Evonok, 1978).

The biggest difference between the unacclimated and acclimated subjects was the difference in heart rate response after submersion and pressurization. At rest, heart rates were essentially the same, however, at depth the heart rate of acclimated divers decreased while the unacclimated divers' heart rates increased. (No difference was found between rectal temperatures of both groups, and these results could not be explained by the researchers). The decrease of heart rate in the acclimated divers demonstrated the typical diving bradycardia reflex. For the unacclimated group, it was apparent that the initial response to thermal stress had an overriding effect on the diving bradycardia reflex. At the end of the dive the heart rate for both groups at both pressures increased about 10 to 15% from the midpoint value. This response was due to the thermal stress (Clingman and Evonok, 1978).

The study delineated the apparent effects of pressure when superimposed on cold stress. An increase in all the physiological variables measured, with the exception of breathing frequency was observed, with an increase of pressure from 2 to 3 ATA. The increase in heart rate, oxygen consumption, heat debt, and minute ventilation at 3 ATA seemed to be caused by the pressure increase, which squeezed the insulating qualities of the diving suit, and decreased thermal protection. The combined effects of cold and pressure appear to severely limit the efficiency and bottom time of divers, especially with increasing depth, and is particularity true for the unacclimated diver (Clingman and Evonok, 1978).

Factors in Diving Accidents.

Scuba diving is a high risk activity. Among the popular more hazardous sports, only parachuting and hang gliding have higher mortality rates. More than 25 percent of the fatalities occur in young male divers who are presumed to be at the peak of their fitness.

Although the frequency of dives and the exact number of recreational divers at risk is unknown, the statistics do indicate that the recreational diver has a much higher incidence of problems or accidents than seen among the professional or military divers (Shilling, Carlston et al., 1984).

An aspect of diving that needs to be addressed more closely when one is trying to determine a diver's susceptibility to diving accidents is his/her physical and emotional state and how it may interplay with environmental factors. Generally, diving accidents are not a result of one thing going wrong, but instead a cascading of problems which lead to a panic situation or an accident. Factors to consider in the environment are: depth (pressure); breathing mix (PN_2, PO_2, PCO_2); equipment fit or function; water temperature; current; and visibility. Mental factors which play a role in diving mishaps are: experience, anxiety, intelligence, training, and susceptibility to panic. During immersion, a properly weighted diver feels a sense of weightlessness. This state of neutral buoyancy is achieved by modifying various pieces of equipment to the body and the body's position in the water. Achieving neutral buoyancy allows a diver free access to move in a horizontal plane with ease. Although the state of neutral buoyancy allows for freedom of movement, it can create severe anxiety in response to the sensory deprivation accompanying a dive in water with little or no visibility. Lastly, the physical factors which affect the safety of a diver are: exercise capacity; age; sex; and body composition. Each factor in each category can easily interact with any other factor or factors. Understandably, the types and numbers of different possible combinations are very large and the relative contribution of any single element is often difficult to determine (Shilling, Carlston et al., 1984).

Most accidents are caused by the following problems: behavior-panic in a minor emergency; failure of the buddy system; overestimation of one's ability; environmental factors including (high surf, poor visibility, strong currents, seasickness, cold water, inability to surface (cave), marine animals, and barotrauma); disregard or underestimation of the limits of deep and long dives; and equipment-unfamiliarity (poor fit and malfunction) (Azasa and Cooper, 1982).

Preexisting medical illness has been directly implicated in 4.5 percent of fatalities. More important factors to be considered are the divers ability to handle stressful situations; prior training; current aquatic skills; knowledge of dive site; observance of safety precautions; and physical fitness. Azasa and Cooper (1982) suggest that the assessment of a diver's fitness should be individualized, with consideration of both physical and psychological status.

Divers now make up a larger subgroup of the normal population seen by some doctors. Thus there is a need to re-evaluate the "normal" values of important physiological measurements for the diving population. The ventilatory system is of major concern since it is stressed continuously during diving, and hence may be expected to show changes related to the diving history of each individual. Usually divers are judged fit or unfit based on norms for the nondiving population, and we now are aware that these standards are not appropriate (Climsit and Flook, 1981).

In summary, the safety of every diver is very dependant on several factors: prior diet; physical and emotional state; age; body composition; stress; previous training; physical fitness; environmental factors; equipment; current aquatic skills; knowledge of dive site; diving experience; and observance of safety precautions. Because of this, safe diving does not entail only donning the equipment and jumping into the water. Divers need to consider and design a comprehensive approach which helps to prevent accidents or fatalities. Accidents do happen. However, if divers made it their responsibility to address their own limitations and those of the particular diving environment they might find their dives to be safer and more enjoyable.

Because of the dearth of information available to date on the effects of cold and warm water exposure on recreational divers, this author proposes to study the specific cardiovascular, respiratory, and energy expenditure responses of older male recreational divers.

CHAPTER THREE

METHODOLOGY

The purpose of this study was to determine the physiological changes that occur in certified scuba divers while submerged (finning) in cold and warm water with and without thermal protection. This chapter has been divided into these sections: (1) Selection of subjects; (2) Experimental conditions; (3) Instrumentation; (4) Pilot study and experimental procedures; (5) Statistical procedures;

Selection of Subjects

Fifteen certified scuba divers residing in Oregon between September and October 1988, volunteered to participate in this study. The procedure for selecting subjects consisted of obtaining names and numbers of male divers in the community from the local dive store's mailing lists, flyers, newsletters, and newspaper articles. Factors used in selection of subjects were: age, medical history, sex, and diving experience. Healthy males 33 to 50 years of age who dove no more than 45 times within the last year were selected. All signed the Informed Consent form (Appendix D). All were informed of the nature and type of tests they were to perform, and agreed to participate.

Experimental Conditions

The subjects participated in five experimental conditions:

1). A symptom limited, maximal graded exercise tethered finning test. Values for heart rate, and oxygen consumption (VO_2), and maximal weight supported in a tethered system were obtained and used to determine each subject's maximal aerobic capacity under finning conditions (29 °C water temperature, without wet suits).

2). A submaximal (35% of maximal workload) underwater finning test in a pool (29 °C) at a depth of approximately 1 foot without wet suits.

3). A submaximal (35% of maximal workload) underwater finning test in a pool (18 °C), at a depth of approximately 1 foot without wet suits.

4). A submaximal (35% of maximal workload) underwater finning test in a pool (29 °C) at a depth of approximately 1 foot with wet suits.

5). A submaximal (35% of maximal workload) underwater finning test in a pool (18 °C), at a depth of approximately 1 foot with wet suits.

Work Intensity

The workload required of the divers during the submaximal tests was designed to simulate (as close as possible) the exercise intensity employed by an average recreational scuba diver. Webb (personal conversation, 1988) stated that recreational divers generally work at an intensity of 35 to 40 % of their maximal water aerobic capacity. To determine maximal aerobic capacity from which the 35 to 40% workload could be calculated, a tethered finning system was designed which consisted of a pulley and rope system, attached at one end to a weighted basket, and at the other end to the diver's weight belt (Appendix B). Each diver started the test by finning against the backward pull of the tethered system (which was attached to the basket loaded with a 5 pound (2.3 kg) weight. Divers were given instructions to fin against the backward pull of the weighted tethered system. They were also instructed to maintain body position with respect to a marker at the bottom of the pool. The divers were asked to continue finning, while maintaining their position against the increasing backward pull due to the addition of weight in the basket at the end of every two minute period. The maximum weight sustained during the graded maximal test was used to calculate the 35% work load used in the submaximal tests.

The author decided to use 35% of the maximum weight pulled as the workload employed. Regulating the relative (35%) workload by putting a fixed amount of weight in the basket for each diver provided more accuracy in maintaining a standard (fixed) intensity.

This procedure was used rather than using 35% of the maximal VO_2 because 35% would actually be accurate only if employed during diving in the same environment. Having to calculate a 35% VO_2 workload for every diver, for every dive condition would have entailed performing four maximal graded tethered finning tests under the four different dive conditions. This would obviously require much more testing time for both the researchers and divers, and create problems because there was a limit on pool time and diver availability.

The problem with fixing the workload at the chosen 35% max. (as was done in this test) is that this level may in fact not represent the work intensity of a diver who participates, for example, in very cold water spear fishing or very warm water underwater photography. The question still remains as to whether 35-40% of max is truly representative of the workload encountered while engaged in recreational diving. If in fact the average recreational dive/finning intensity is greater or less than 35% of maximum VO_2, then the results of this particular experiment would be different, and may not represent what occurs during recreational diving.

Water Temperature Regulation

Another problem was trying to simulate normal diving situations while at the same time collecting accurate information. When trying to compare warm water diving without suits to cold water diving with suits, there is the problem of trying to decipher whether the differences found between the two situations are in fact due to the water temperature or to some other variable, in this case the addition of a wet suit. In handling this problem, the researcher decided to implement four experimental conditions; with and without suits, warm and cold water. The next problem encountered was water temperature. What temperature can researchers subject divers to (with and without wet suits) during a 30 minute or longer submaximal finning session, without neglecting the safety of the subjects? Webb (personal communication, 1988) stated that the warm water temperature should be set at about 28 °C to 29 °C, and the cold water temperature at about 18 °C. Webb stressed that subjects would not tolerate such low intensity exercise (35% max.) in water temperatures much below 18 °C for longer than the planned thirty minutes.

Wet Suit Utilization

The cold water temperature (18 °C) may not provide a cold stress to the diver diving with thermal protection. In addition the 18 °C water temperature may not accurately simulate some cold water diving situations (as would be found in some bodies of water). Recreational divers do however dive year around in lakes, rivers, streams, quarries, and oceans. The water temperature in each of these environments can fluctuate as much as 20 °C during different seasons of the year. A body of water can also have one or several thermoclines which would allow a diver to dive in temperatures that are two to ten degrees different at different depths of their dive. Many times divers encounter colder temperatures as they descend, however, this is not always true. Some lakes and quarries go through seasonal changes and water inversions which produce several thermoclines, with the colder water temperatures being found near the surface and the warmer water deeper down.

During the water testing each subject was given ample time to become familiar with the equipment and pool environment prior to the first maximal tethered finning test. The divers completed the warm water dives by starting without wet suits. They completed the cold water dives by starting with wet suits. Some of the divers completed their two warm water dives first while some dove twice in the cold water first. In each case they performed the dive wearing the equipment they would normally wear for diving.

Prior to testing, each subject abstained from strenuous exercise for three days and from food for three hours. Each subject kept a three day diet log prior to each test. Since each diver had various schedules, five dove in the morning and ten in the late afternoon and evening. However, the dive times were standardized for each subject. Subjects were allowed one day's rest between the maximal finning test and all other experimental dives.

During the water tests, subjects were prepped (prior to donning equipment) with a heart rate monitor, rectal temperature probe, and introduced to the expiratory gas collection valves and hoses. Subjects were allowed ample time to check and don the remainder of their scuba equipment, then allowed time to become familiar with the water, attain enough buoyancy to keep them just below the surface of the water, and to be attached to the tethered swimming system. Subjects were accompanied into and under water by an experienced diving instructor who acted as their buddy and helped to properly equip them prior to testing (the diving instructor remained the same throughout the testing). Prior to starting the finning tests, divers were asked whether everything was "all right" by using the appropriate hand signal for "O.K."

Each subject received specific instruction as to the protocol during the finning tests. During the water tests subjects were instructed to maintain body position (as related to an underwater marker) as the finning workload was increased to the specific workload (35% maximum workload). The workload remained fixed, and values for breathing frequency, minute ventilation, oxygen consumption, respiratory exchange ratio, heart rate, and core temperature, were obtained and recorded every two minutes. The researcher stressed that the subjects continue finning as long as they physically could or until the end of the 30 minute time period during the four finning exercise tests. As soon as the diver was unable to maintain body position (against the backward pull of the workload) or when the water temperatures became too thermally stressing for them, the test was terminated. Divers were instructed to terminate finning if they encountered cramping, dizziness, breathing difficulty, severe anxiety, disorientation, extreme heat, or extreme cold.

At the end of the test, divers were signaled to slow down their finning speed, they then ascended directly to the surface and exited the pool.

No subject was allowed to enter the water if his equipment was worn in a manner which was considered unsafe. Nor were they allowed to complete or continue any test if his performance indicated that his safety was jeopardized.

During this study subjects also performed forced vital capacity maneuvers and were then underwater weighed. Vital capacity was obtained using an Ohio 827 dry rolling spirometer, interfaced to an Apple II E computer which was running the pulmonary fuction testing software from Vacu-Med. (Ventura, California). Estimation for residual volume was made by taking 24% of the subjects vital capacity (McArdel, Katch et al., 1986). Body density was obtained from hydrostatic weighing. Body percent fat was calculated using Digit Health Software (Seri equation, Lenard Kaufman, Lake Oswego, Oregon). Hydrostatic weighing first involved weighing all subjects on a Homs full capacity beam scale, model 300 AD, calibrated to the nearest 1/10 lb. During the underwater weighing, all subjects were seated in a chair which was suspended from a Masstron Scale Inc. Load cell (type ml 2210) attatched to a 1/4 Ton Jet mechanical crank (Model 3192502221). The load cell was interfaced with a Toledo scale digital screen, (model 8140). The chair which the subjects were seated on was suspended into a stainless steel water tank, where the water temeprature was maintained at 36 degrees C. Five trials of hydrostatic weighing at residual volume were administered according to the procedures of Katch (1968), and the average of the three highest trails was used in the calculation for percent body fat.

Instrumentation

The graded maximal finning test was conducted in the Women's Building pool at Oregon State University using standard open spirometry procedures. Oxygen concentrations were analyzed with an electrochemistry SA3 O_2 analyzer. Carbon dioxide concentrations were analyzed with the Beckman CO_2 infrared analyzer. Gas analyzers were calibrated prior to each test using standard reference gases. Ventilation was measured using a Parkinson Cowan CDX gas meter. All instrumentation was interfaced with an Apple IIe microcomputer. Heart rates were monitored with a water proof telemetry system. The Bio-Design Model RX-450A receiver and transmitter were used in conjunction with the Bio-Design NC heart rate monitor Model HR 350. The transmitter was placed inside a water tight, hard plastic container while the two electrodes were fed out of the container through small holes which were then sealed and made water proof with cyanoacrylate (Super Glue).

During the water tests each subject wore the same diving equipment in both warm and cold water (Appendix A). The equipment included: mask, nose clip, open heeled adjustable fins, 71.2 cubic inch tank (2500 p.s.i.), jacket buoyancy compensator, booties, and weight belt. A 1/4" wet suit (farmer john), hood, and gloves were worn in addition to the above gear during the dives with wet suits.

Gas exchange collection equipment consisted of a one-way Daniels breathing valve which was connected to an inspiratory and expiratory 12 foot gas collection hose (2 1/4" in diameter) with a mouth piece fitting. The gas collection hose extended onto the pool deck and was assembled in-line to the gas meter and via a mixing chamber to the O_2/CO_2 analyzers for gas collection and analysis.

Temperature monitoring equipment consisted of a specially designed Yellow Springs Institute underwater rectal thermometer. The thermistor was calibrated prior to testing and readings were compared to an accurate thermometer. The rectal thermometer was held in place with surgical tape under the swim suit and or wet suit and hard wired to the surface telemeter.

The four finning tests which followed the maximal finning test were also carried out at the Women's Building pool at Oregon State University. The temperature remained constant at 29 °C for the warm water tests and constant at 18 °C for the cold water tests.

Pilot Study and Experimental Procedures

Prior to the actual study, several pilot studies were conducted. The primary investigator tested each of the following (underwater at a depth of two feet): the heart rate monitor, the temperature thermistor, the expired air collection hoses, and the tethered swimming system. The pilot studies were conducted in the same manner as that of the final study. However only one subject was used in each of the six tests. All equipment used and procedures followed were as outlined above.

Statistical Procedures

The raw data obtained was analyzed with a Four-Way Analysis of Variance and Repeated Measures design. When there was significant interaction found for time, temperature, or suit conditions the statistical procedure for Newman-Keuls (Kirk, 1982) was employed to determine where the specific significant interactions(s) took place. The alpha level was set at 0.05. The number of subjects used was 15.

The statistical package BMDP was used in the Four-Way analysis of Variance and Covariance with Repeated Measures for each of the following variables in the warm and cold water, with and without wet suit dives: 1) Breathing Frequency (breaths per minute); 2) Minute Ventilation (liters x min^{-1}); 3) Oxygen Consumption (liters x min^{-1}); 4) Oxygen Consumption (milliliters x min^{-1} x kg^{-1}); 5) Respiratory Exchange Ratio (R.E.R.); 6) Heart Rate (H.R., beats per min); and 7) Core Temperature (T °C). The covariate was percent body fat (for each of the divers) (Table I & II, for statistical results). The results also include the calculated caloric expenditure (k/cal) for each dive which was derived from the respiratory exchange ratio and oxygen consumption using a nomogram (McArdle, Katch et al., 1986). However caloric expenditure values were not compared statistically.

CHAPTER IV

RESULTS

The purpose of this study was to investigate: breathing frequency; minute ventilation; oxygen consumption; respiratory exchange ratio; caloric expenditure; heart rate; and core temperature in certified recreational Scuba divers who dove in warm and cold water with and without wet suits. Any differences identified in the dependent variables listed above during the fixed workload in response to the specific diving environment could play an important role in recommendations and regulations which govern recreational Scuba divers. The results from this investigation have been organized as follows: Inferential Statistics, which includes the hypotheses, the Four Way Analysis of Variance, Newman-Kuels, and the discussion of results (for each dependent variable).

Inferential Statistics

The statistical package BMDP was used in the analysis of variance and covariate with repeated measures for each of the following variables in the warm and cold water, with and without wet suit dives: 1) Breathing Frequency (breaths per minute); 2) Minute Ventilation (liters x min^{-1}); 3) Oxygen Consumption (liters x min^{-1}); 4) Oxygen Consumption (milliliters x min^{-1} x kg^{-1}); 5) Respiratory Exchange Ratio (R.E.R.); 6) Heart Rate (H.R., beats per min); 7) Core Temperature (T °C). The numerous means and standard deviations for each of the dependent variables are found in Appendix G-M. The covariate was percent of body fat (for each of the divers) (see Table I). The results also include the calculated caloric expenditure (k/cal) for each dive, which was derived from the respiratory exchange ratio and oxygen consumption using a nomogram (McArdle, Katch et al., 1986) (Appendix, N).

Table I. Diver Characteristics

DIVER	AGE YRS	HT. CM	WT. KG	% Body FAT	NO. DIVES	YEAR CERT.	VO_2 $mlxKg^{-1}xmin^{-1}$	S.A. m^{-2}	W/H^2
1	50	175.0	83.2	30.1	45	1985	27.75	1.99	27.2
2	36	175.0	96.4	29.3	38	1977	35.81	2.12	31.5
3	41	175.0	82.7	18.9	25	1987	36.54	1.98	27.0
4	40	182.5	81.4	21.9	20	1988	34.81	2.02	24.4
5	37	185.0	85.0	9.8	6	1988	37.79	2.00	24.8
6	43	180.0	72.3	18.8	20	1980	39.60	1.92	22.3
7	37	175.0	94.1	30.4	46	1982	28.70	2.10	30.7
8	39	175.0	85.9	21.7	300	1975	43.79	2.02	28.0
9	34	180.0	85.9	24.1	35	1985	30.11	2.06	26.5
10	36	177.5	82.7	12.5	44	1986	29.49	2.01	26.2
11	33	167.5	102.7	34.5	38	1983	20.17	2.10	36.6
12	35	172.5	76.8	22.0	60	1984	33.15	1.91	25.8
13	35	175.0	82.7	19.8	300	1984	27.88	1.98	27.0
14	45	176.5	77.7	23.2	1000	1962	35.25	1.95	24.9
15	36	170.0	76.4	22.6	30	1984	27.27	1.88	26.4
Mean	38.5	175.5	84.4	22.4	133.8	---	32.54	3.00	27.3
S.D.	5.6	1.53	7.81	4.02	304.6	---	72.25	3.96	33.9

Descriptive data for each of the fifteen divers. Age, height, weight, percent body fat, total number of dives, maximal VO_2 values, body surface area (m^2), and height divided by weight squared are presented.

When there was significant interaction found for time, temperature, or suit conditions, the statistical procedure for Newman-Keuls

(Kirk, 1982) was employed to determine where the specific significant interaction(s) took place.

It should be noted that the first five minutes of diving in most cases was significantly different than the other time periods for the dependent variables during each of the four dives. It appeared that the subjects took the first few minutes of diving to become accustomed to the particular diving environments, and did not relax to achieve a steady state until four or five minutes into each test. For this reason, attention was focused on analyzing the results which depict the last 25 minutes of testing.

Breathing Frequency (B.F., Breaths per Minute)

Hypothesis 1

Statistical analysis resulted in the acceptance of the first hypothesis: there were significant differences found between breathing frequency (breaths per minute) during cold versus warm water diving with and without wet suits.

Significant treatment differences were evident at the (averaged) 5 minute intervals over the 30 minute test for the various suit conditions, regardless of the water temperature.

The breathing frequency under each of the four experimental conditions over the 30 minute period of finning is presented in Figure 1. The standard error for breathing frequency was found to be 0.51 for all four conditions. The standard deviation for breathing frequency was found to be ± 3.1 for the 29 °C water dive without suits,

± 4.0 for the 29 °C water dive with suits, ± 3.4 for the 18 °C water dive without suits, and ± 3.0 for the 18 °C water dive with suits. The 24 mean breathing frequency and standard deviation values for the six (five minute averages) time periods for each of the four diving conditions are found in Appendix G.

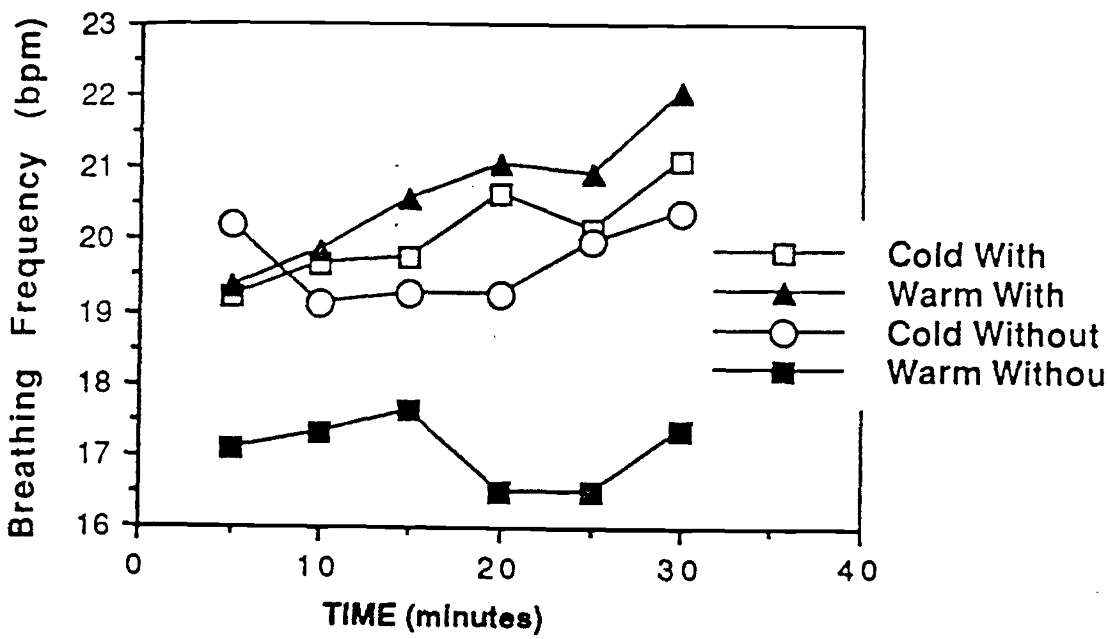

Figure 1. Breathing frequency responses during the four diving conditions.

There was a significant Two-Way interaction ($p < 0.0366$) found for time x temperature, so the Newman-Keuls statistical procedure was used to determine where the specific significant interaction took place. There was no significant Three-Way interaction found between suit use and water temperature over time. Water temperature did not influence breathing frequency, and the interaction occurred for suit use over time (Figure 2). The standard deviation for dives without suits was ±3.6, while the standard deviation for dives with suits was ±3.5.

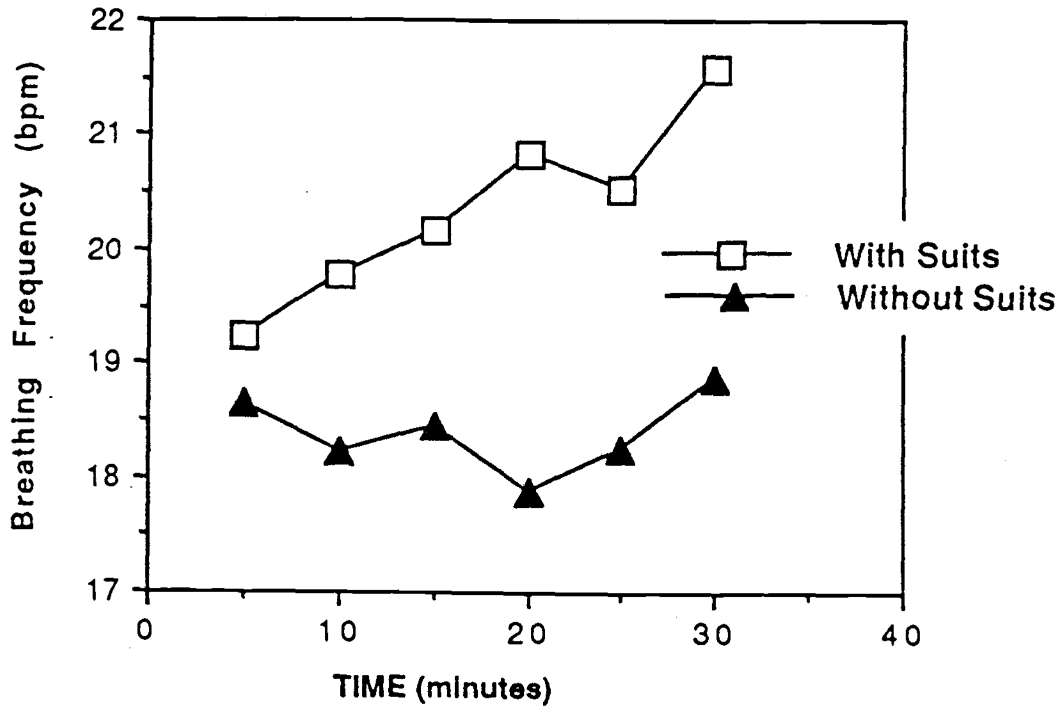

Figure 2. Breathing frequency responses during with and without suit conditions

The only significant difference found was between the two lowest breathing frequency means (minutes 6-10, and 21-25) without wet suits and the three highest (last ten minutes of diving) with wet suits. It is interesting to note, although not significant in every case, that of the total 12 mean breathing frequency values, the six lowest values were all dives without suits and the remaining six highest values were all for dives with suits.

These results suggest that diving without extra thermal protection, as compared to diving with protection, produces lower breathing frequencies in divers. This decrease in breathing frequency occurred regardless of temperature, and despite the fact that the workload remained the same in each of the diving conditions. It could be hypothesized that wet suits pose a restriction to respiratory movement causing resistance to chest wall expansion producing a smaller tidal volume. The diver reacts to the decrease in chest wall expansion by taking smaller and more frequent breaths to meet the demands of the exercise intensity and the specific diving environment. Increases in minute ventilation result from either an increase in the depth or rate of breathing, or both (McArdle, Katch et al., 1986, Coates, 1970).

Physical activity affects oxygen consumption and carbon dioxide production more than any other form of physiologic stress (Dempsey, Hanson et al., 1982). In light to moderate exercise, ventilation increases linearly with oxygen consumption. During exercise, alveolar ventilation is maintained through an increase in both the rate and depth of breathing. Usually, during moderate exercise adequate alveolar ventilation is achieved by increasing tidal volume with only a small increase in breathing rate. It is found that during more intense exercise, tidal volume increases start to plateau and minute ventilation is further increased through an increase in breathing frequency. Therefore, considering that the finning intensity employed during testing (35% max) was moderate, one would not expect to see increases in breathing frequency as was observed during the "with suit" dives. These results suggest that the increases in breathing frequency were elicited by the use of the wet suits and not due to the workload of finning at 35% max. It appeared that each diving condition placed the diver in different environments which produced the different breathing frequencies and $\dot{V}_E$ depending on whether wet suits were worn and on thermal stress. Specifically, the dives with wet suits elicited an increase in breathing frequency when compared to the dives without wet suits.

Minute Ventilation ($\dot{V}_E$, BTPS)

Hypothesis 2

Statistical analysis resulted in the acceptance of the second hypothesis: there were significant differences found between ventilation volume ($\dot{V}_E$ L x min^{-1}) during cold versus warm water diving with and without wet suits.

Significant treatment differences were evident at the (averaged) 5 minute intervals over the 30 minute test for the various diving conditions (warm with, warm without, cold with, and cold without).

The minute ventilation under each of the four experimental conditions over the 30 minute period of finning is presented in Figure 3. The standard error for minute ventilation was found to be 0.582 L x min^{-1} for all four dives. The standard deviation for $\dot{V}_E$ was found to be $\pm$4.6 for the 29 °C water dive without suits, $\pm$4.2 for the 29 °C water dive with suits, $\pm$6.1 in the 18 °C water dive without suits, and $\pm$3.6 in the 18 °C water dive with suits. The 24 mean minute ventilation and standard deviation values for the six time periods during each of the four diving conditions are found in Appendix H. There was a significant Three-Way interaction ($p < 0.0075$) found for suit x temperature x time so the Newman-Keuls statistical procedure was used to determine where specific significant interaction took place.

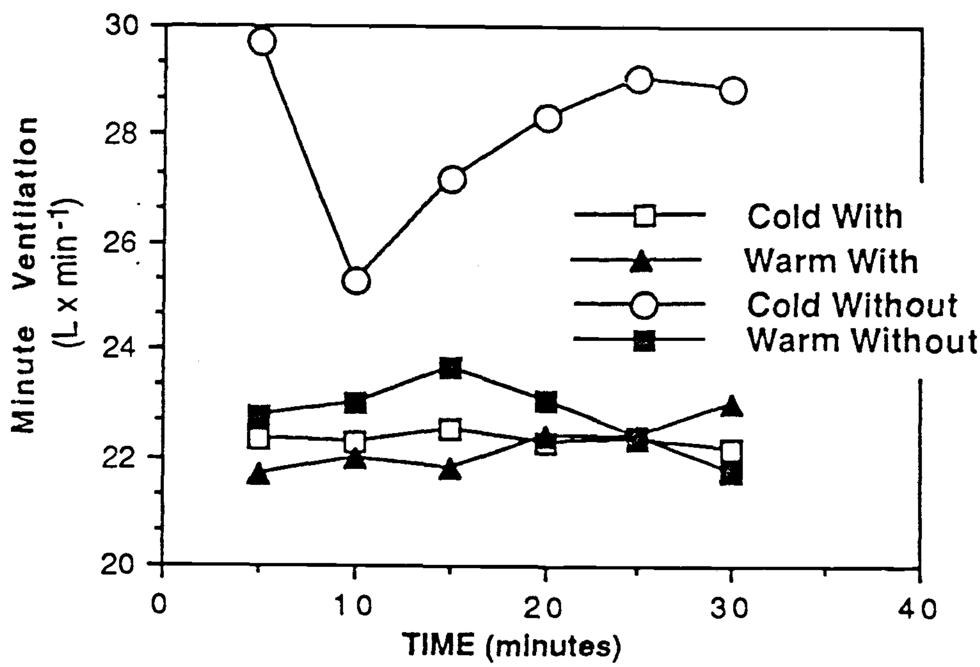

Figure 3. Minute Ventilation responses during the four diving conditions.

The highest value for $\dot{V}_E$ noted was 29.69 L x min^{-1} in cold water without a suit and the lowest (21.69 L x min^{-1}) was observed in warm water with a wet suit. Although there were numerous significant differences found between the five minute averages during the various dives, it is important to note the narrow range and standard deviation of $\dot{V}_E$ within each diving condition (Figure 3).

Minute Ventilation for each Condition

The $\dot{V}_E$ during the warm water dive with suits ranged from 21.69 L x min^{-1} to 22.98 L x min^{-1}; the $\dot{V}_E$ during the warm water dive without suits ranged from 21.71 L x min^{-1} to 23.64 L x min^{-1}. The $\dot{V}_E$ during the cold water dive with suits ranged from 22.14 L x min^{-1} to 22.51 L x min^{-1}, while the $\dot{V}_E$ during the cold water dive without suits ranged from 25.27 L x min^{-1} to 29.69 L x min^{-1}.

The trends over time for each diving condition were slightly different from one condition to the other and there did not appear to be any consistent pattern of increases or decreases for $\dot{V}_E$ over time during any of the four dives. There were similarities between both warm water dives and the cold water dive with suits. The range of $\dot{V}_E$ for each of these dives was very narrow and did not change appreciably during the thirty minutes. This study revealed that $\dot{V}_E$ was highest during those dives which placed the divers under the most thermal stress.

The highest $\dot{V}_E$ was observed during the cold water dive without suits. Due to the stress of the cold water, the divers actually expended more energy during this dive when compared to the other three dives. The $\dot{V}_E$ (all six time periods) for the cold water dive without suits was significantly higher than most other time periods during the other dive conditions regardless of time, temperature, or suit use. The only exceptions to this were found during minutes 6 through 25 in warm water diving without suits, and the last five minutes of diving in warm water with suits.

The highest $\dot{V}_E$ achieved (29.30 L x min^{-1}) was during the first five minutes of diving in cold water without a suit. At this time the divers were usually breathing very frequently. They appeared to be trying to "catch their breath" while adjusting themselves to the cold temperature. After a few minutes underwater they relaxed and resumed a more normal breathing pattern.

The results of this study suggest that the minute ventilation for the divers was not significantly different between dives unless divers were diving in the 18°C water without thermal protection. Under this latter condition their minute ventilation (with four exceptions) was found to be significantly higher than $\dot{V}_E$ values observed during the other diving conditions. During the cold water dive core temperature fell as a result of heat loss exceeding heat production. Shivering occurred in most of the divers, thus total metabolic rate increased. Although metabolic heat is generated through shivering, the greatest contribution of muscle to defense against cold occurs during physical activity. However, the thermoregulatory defense against cold is mediated by internal temperature and not by the heat production in the body per se. Thus, shivering is observed even during exercise if the core temperature is low (as was the case in the cold dive without suits). As a result, exercise oxygen consumption is proportionally higher (due directly to shivering) in cold stress than it is during the same exercise in warmer environments (Craig & Dvorak, 1969, Costill, Cahill et al., 1967). An increase not only in $\dot{V}_E$ but also in $\dot{V}O_2$ during this dive was observed, indicating that the divers were cold stressed. As $\dot{V}_E$ increased there also was a concurrent change in either the rate or depth of breathing to bring about the needed increase in gas exchange. The given $\dot{V}_E$ was determined by the metabolic rate, while the matching of breathing frequency and tidal volume to achieve the given $\dot{V}_E$, was influenced by use of the wet suit.

Ventilation Responses During Normal Diving Conditions

Diving in warm water without wet suits resulted in a slightly higher $\dot{V}_E$ than diving in cold water with wet suits, although not significant. The higher $\dot{V}_E$ values found during the warm water dive without suits when compared to the cold dive without suits, suggested that the warm water dive required a higher level of caloric expenditure. This suggestion was in fact supported by the data for oxygen consumption and minute ventilation from this test (see Figure 4). The results indicated that warm water diving without suits elicited higher caloric expenditure, $\dot{V}O_2$, and $\dot{V}_E$ responses than the cold dive with suits. Based on these observations, it may be useful for divers to wear thermal protection even in warm water dives to minimize increases in minute ventilation, oxygen consumption, and caloric expenditure.

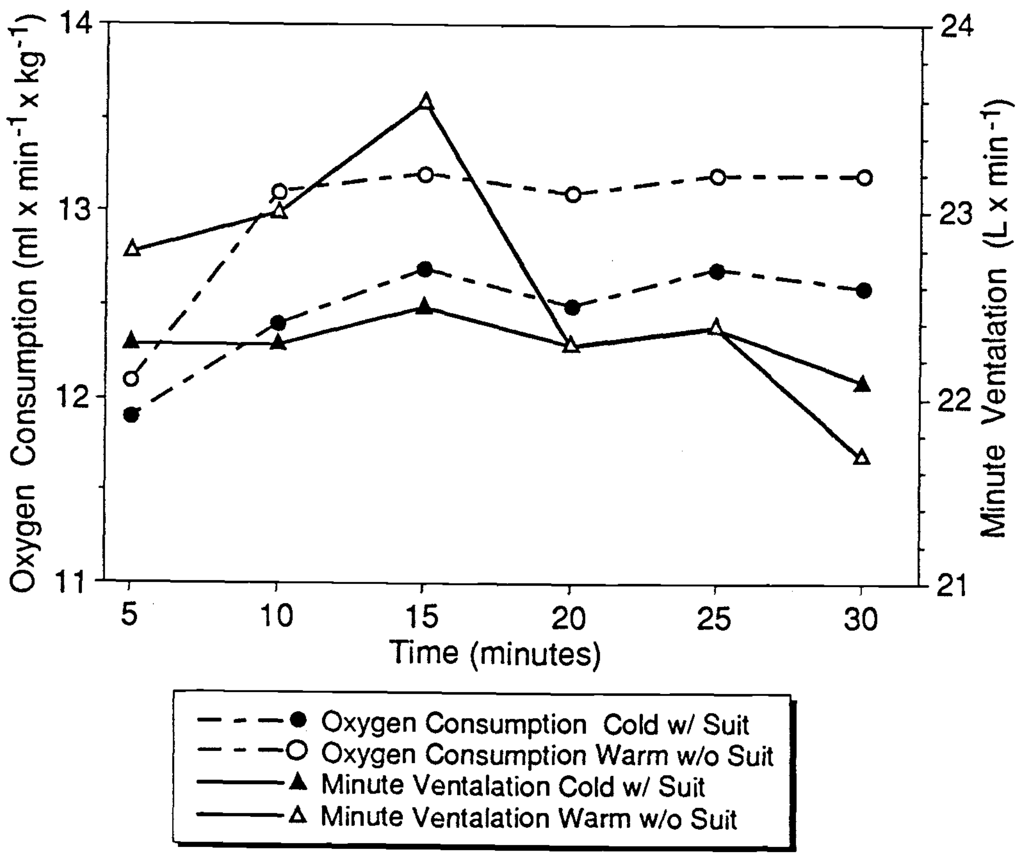

Figure 4. Oxygen consumption and minute ventilation responses during "normal" diving conditions.

Relationship of Ventilation and Breathing Frequency Responses

Diving without suits produced a lower breathing frequency, and higher minute ventilation. Conversely, it was found that diving with suits elicited higher breathing frequency values and generally lower minute ventilation values. It could be assumed that as wet suit restriction decreased normal chest wall expansion, the divers compensated by increasing breathing frequency in order to achieve the minute ventilation needed in order to meet the metabolic demands of the body. Minute ventilation is generally correlated with increases in metabolic requirements. Review of the VO_2 data did in fact show higher values for V_E with increasing metabolic requirements to maintain thermal balance.

Oxygen Consumption (VO_2, Liters per Minute, STPD)

Hypothesis 3

Statistical analysis resulted in the acceptance of the third hypothesis: there were significant differences found between oxygen consumption (VO_2 L x min^{-1}) during cold versus warm water diving with and without wet suits.

Significant treatment differences were evident at the (averaged) 5 minute intervals over the 30 minute test for the various diving conditions (warm with, warm without, cold with, and cold without).

The oxygen consumption in liters per minute under each of the four experimental conditions over the 30 minute period of finning is presented in Figure 5. The standard error for oxygen consumption was found to be 0.016 L x min^{-1} for all four conditions. The standard deviation for VO_2 was found to be $\pm$0.17 for the 29 °C water dive without suits, $\pm$0.22 for the 29 °C water dive with suits, and the 18 °C water dive without suits, and $\pm$0.21 for the 18 °C water dive with suits. The 24 mean VO_2 and standard deviation values for the six time periods during each of the four diving conditions are found in Appendix H. There was a significant interaction ($p < 0.0000$) found for time x temperature x suit. Therefore, the Newman-Keuls

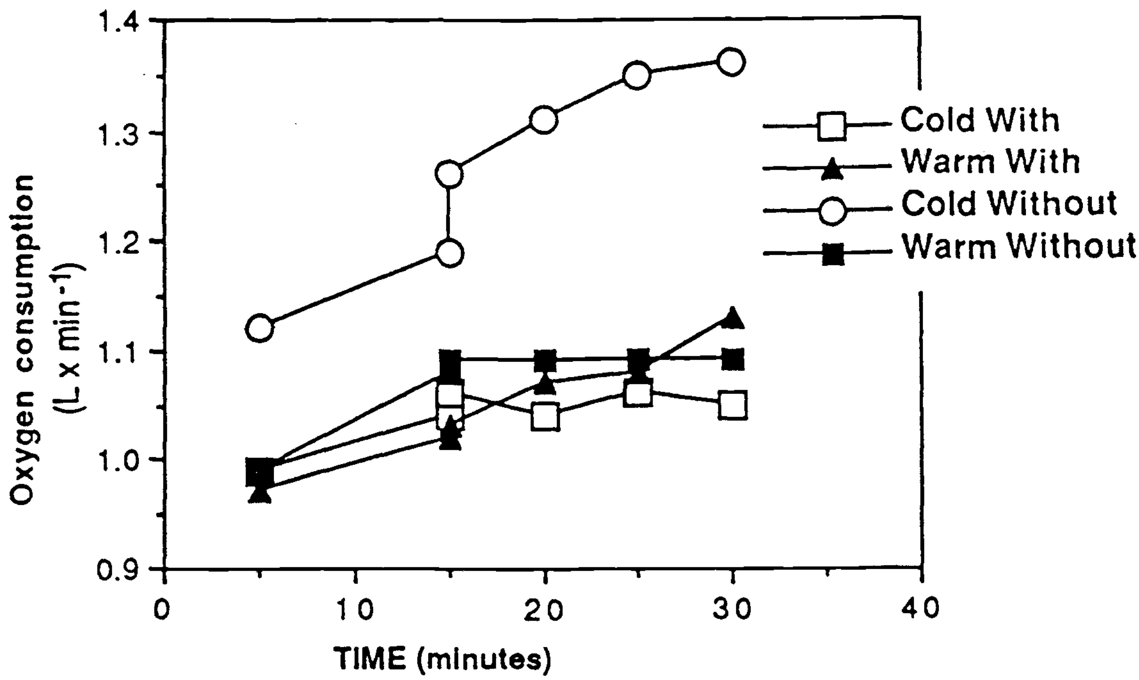

Figure 5. Oxygen consumption responses during the four diving conditions.

statistical procedure was used to determine where the specific significant interaction took place.

Analysis of the data revealed many significant VO_2 differences between each of the various time, temperature, and suit conditions. The general trend was for the VO_2 values to increase from the first five minutes to the last five minutes during the cold dive without wet suits and the warm dive without wet suits. The VO_2 values during both the warm and cold dives with wet suits increased during the first fifteen minutes then plateaued from minute 15 through the end of the tests. Specifically, there was a 6% (non significant) increase in VO_2 during the cold water dive with suits, an 8% (significant) increase during the warm water dive with suits, a 21.4 % (significant) and 10%

(significant) increase in VO_2 during the cold and warm dives (respectively) without suits. These thirty minute trends indicate that the length of time spent in the water and/or the thermal stresses of the environment affected a diver's oxygen consumption in a manner which produced the observed (significant, 3 out or 4 cases) increases over time.

Oxygen Consumption Responses During Cold Water Diving Without Suits

The cold water dive without suits (minutes 6 through 30) produced significantly higher VO_2 values than all other dives regardless of time, temperature, or suit use. These results suggested that diving during cold stress required additional caloric expenditure. The observation that cold water diving without suits required the highest level of caloric expenditure was supported by the literature. During moderate exercise in cold environments, oxygen consumption is higher and body temperature lower compared to identical exercise in warmer water (Craig & Dvorak, 1968). Oxygen consumption and V_E are driven to some extent by core temperature changes and the energy demands of the particular situation. This dive did in fact elicit the highest VO_2, and V_E, values. The lowest core temperature values (significantly lower) were observed during this dive when compared to the other three dives (see Figure 6). The results observed during this study are consistent with data reported in the literature which states that cold stress elicits increased VO_2 (Nadel, Holmer et al., 1974).

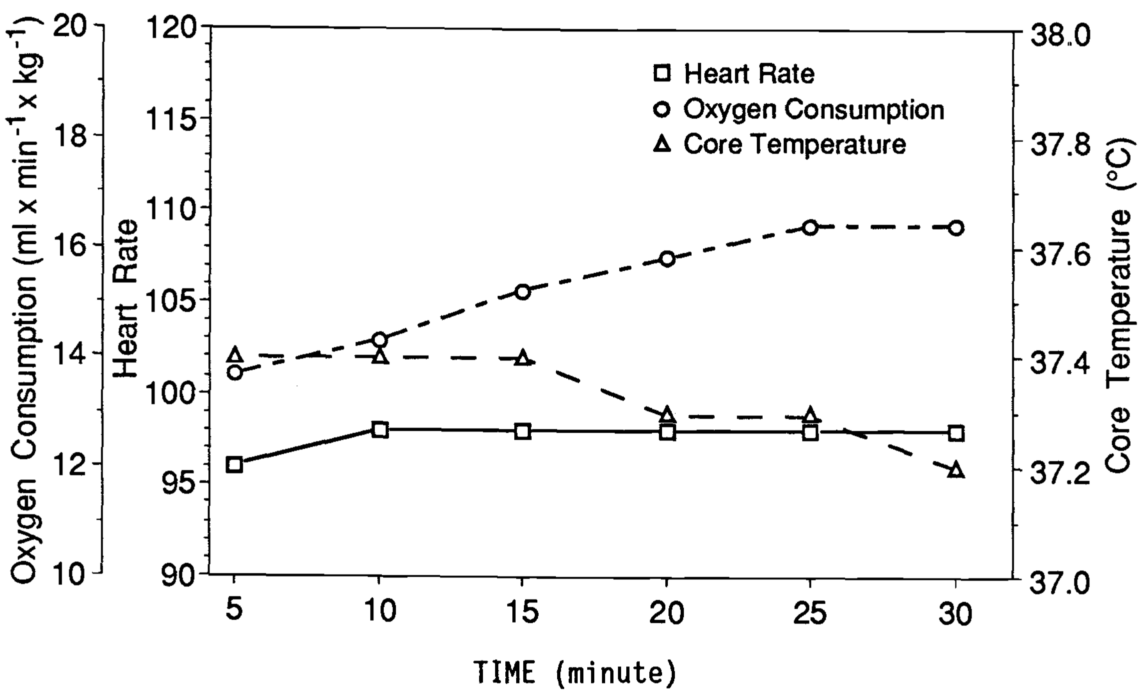

Figure 6. Heart rate, oxygen consumption, and core temperature responses during cold water diving without suits.

Oxygen Consumption Responses While Diving With and Without Suits

Further observation of the results indicated that although not statistically significant (in most cases), 11 out of the 12 highest VO_2 values were produced during dives without wet suits, while 11 of the 12 lowest VO_2 values were observed during dives with wet suits. Diving without suits in either warm or cold water appeared to place the diver under a cold stress which required a higher caloric expenditure. This was reflected in part by the onset of severe shivering and drop in core temperature observed during the coldest dive. The higher caloric expenditure required in cold environments was reflected in the increases in VO_2 and V_E values observed which were driven by the decrease in core temperature and increase in shivering during the cold water dive without suits. The results of the warm water dive without suits indicated a trend towards a small increase in core temperature (37.5 °C to 37.6 °C) during the 30 minute test. These results were somewhat difficult to interpret. The divers may have been slightly heat stressed, as suggested by the small (0.1 °C) rise in core temperature. Heat stress could cause an increase in $\dot{V}_E$ and $\dot{V}O_2$ as a result of the temperature effects on $\dot{V}_E$ and the increased energy requirements to dissipate excess heat. On the other hand, divers were possibly cold stressed. Cold stress could cause an increase in $\dot{V}_E$ and $\dot{V}O_2$ due to slight shivering and the additional energy requirements. If this second hypothesis were true, it might be assumed that the rise in core temperature occurred as a consequence of vasoconstriction at the body's extremities as a means of conserving heat in the face of a heat loss. The observed higher oxygen consumption, minute ventilation, caloric expenditure values, and lower heart rates support the latter hypothesis.

Oxygen Consumption Responses During Normal Diving Conditions

When comparing the normal diving situations (warm without thermal protection and cold with protection) only the first five minutes of diving in cold water with suits produced significantly lower $\dot{V}O_2$ values than all other time periods during the warm water dive without suits. Generally, the warm water dive without suits produced higher $\dot{V}O_2$ values than found during the cold water dive with suits. Nadel, Holmer et al. (1974) indicated that cold water exposure produces higher $\dot{V}O_2$ values than warm water exposure because of the higher caloric expenditure required by the body as it attempts to maintain normal core temperatures in the face of heat loss in the cold environment.

The results might be explained by hypothesizing that diving without a suit (even in warm water) requires a higher level of caloric expenditure by the body, in its attempt to maintain thermal balance. The increase in caloric expenditure is reflected in the observed increase in $\dot{V}O_2$. If warm water diving without thermal protection does create a cold stress for the divers, one might expect to see even greater increases in oxygen consumption (over time) if the divers were to dive for extended periods of time, and/or, if they were to participate in several dives during one day. Usually, participation in several dives in one day will cause a slow but gradual loss of body heat (lowering of core temperature) which would result in an increased need for caloric expenditure as the body tries to maintain thermal balance.

Oxygen Consumption ($\dot{V}O_2$, Milliliters per Minute per Kilogram, STPD)

Hypothesis 4

Statistical analysis resulted in the acceptance of the third hypothesis: there were significant differences found between oxygen consumption ($\dot{V}O_2$ ml x min^{-1} x kg^{-1}) during cold versus warm water diving with and without wet suits.

The oxygen consumption (ml x min^{-1} x kg^{-1}) under each of the four experimental conditions over the 30 minute period of finning is presented in Figure 7. The standard error for oxygen consumption was

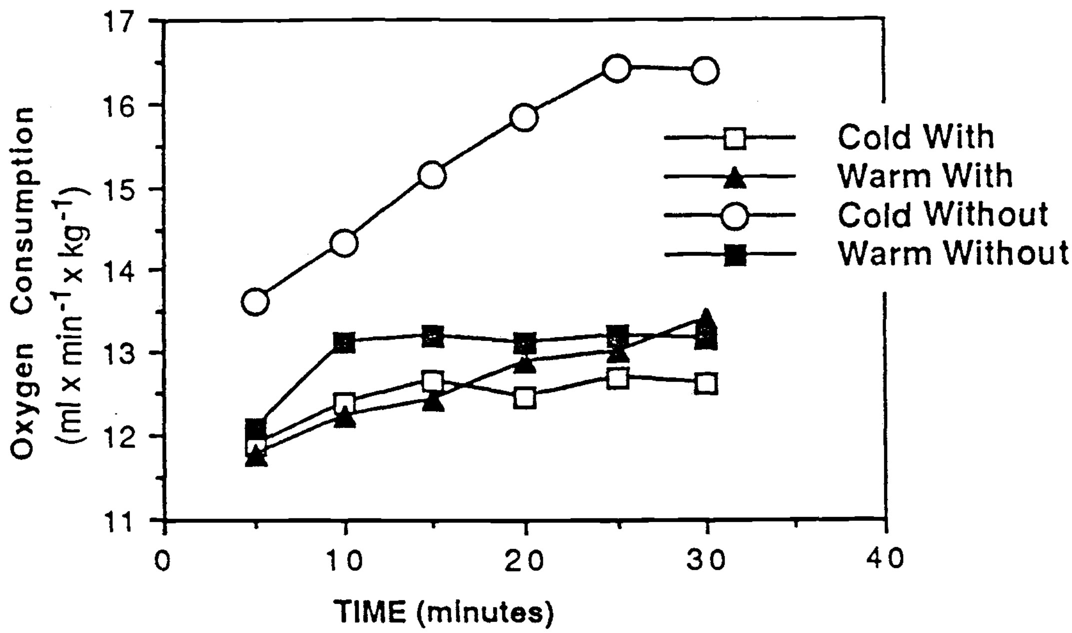

Figure 7. Oxygen consumption responses during the four diving conditions.

found to be 0.203 ml x min^{-1} x kg^{-1} for all four conditions. The standard deviation for VO_2 was found to be $\pm$2.5 for the 29 °C water dive without suits, $\pm$2.6 for the 29 °C water dive with suits, $\pm$3.2 for the 18 °C water dive without suits, and $\pm$2.6 for the 18 °C water dive with suits. The 24 mean VO_2 and standard deviation values for the six time periods during the four diving conditions are found in Appendix J. There was a significant Three-Way interaction ($p < 0.0000$) found for time x temperature x suit, therefore, the Newman-Keuls statistical procedure was used to determine where the specific significant interaction took place. The mean VO_2 values ranged from a low of 11.8 ml x min^{-1} x kg^{-1} (first five minutes, warm water with suits) to a high of 16.4 ml x min^{-1} x kg^{-1} (last five minutes, cold water without suits) for all times, temperatures and suit conditions.

The mean oxygen consumption values increased significantly during three of the four thirty minute dives (the VO_2 during the cold water dive with suits did not increase significantly). The VO_2 values during the cold water dive without suits and the warm dive with suits steadily increased over time, while the VO_2 during the warm water dive without suits increased during the first fifteen minutes then plateaued during the last fifteen minutes. The VO_2 also increased during the first fifteen minutes in the cold water dive with wet suits and then plateaued during the last fifteen minutes. The six highest individual VO_2 values were all observed during the cold water dive without wet suits. The warm water dive without suits produced five of the next highest VO_2 values. The six lowest individual VO_2 values were all produced during the dive in cold water with suits and warm water with and without suits (various time periods).

Oxygen Consumption Responses During Cold Water Diving Without Suits

The cold water dive without suits produced significantly higher mean VO_2 values and the largest percent increase (18%) in VO_2 over time compared to all other times and dives.

The results suggested that divers immersed in 18 °C water with no thermal protection are under greater cold stress when compared to the other three dive conditions. As core temperature decreased significantly during this dive, there was a concurrent rise in caloric expenditure and in oxygen consumption. This data supported the hypothesis that cold water diving without thermal protection posed the greatest cold stress to divers.

Resting VO_2 increases linearly with decreases in core temperature up to about 1.5 liters per minute. This increase in oxygen consumption is a direct result of shivering. Changes in skin and core temperature along with the physical and physiological characteristics of the subjects, in part, contribute to VO_2 responses and changes (Nadel, Holmer et al., 1974). In the case where divers are performing a fixed workload, it can be assumed that if an increase in oxygen consumption and a decrease in core temperature was observed, the workload sustained by the diver was not intense enough to generate adequate heat to maintain thermal balance. With greater heat loss and inadequate heat production, core temperature will not be maintained. As the core temperature falls, caloric requirements increase and oxygen consumption rises (see Figure 8).

<u>Oxygen Consumption Responses During Warm Water Diving With Suits</u>

The added heat stress of diving with a suit in warm water appeared to be great enough to cause a (significant) fourteen percent rise in VO_2 over time. During diving conditions where either the

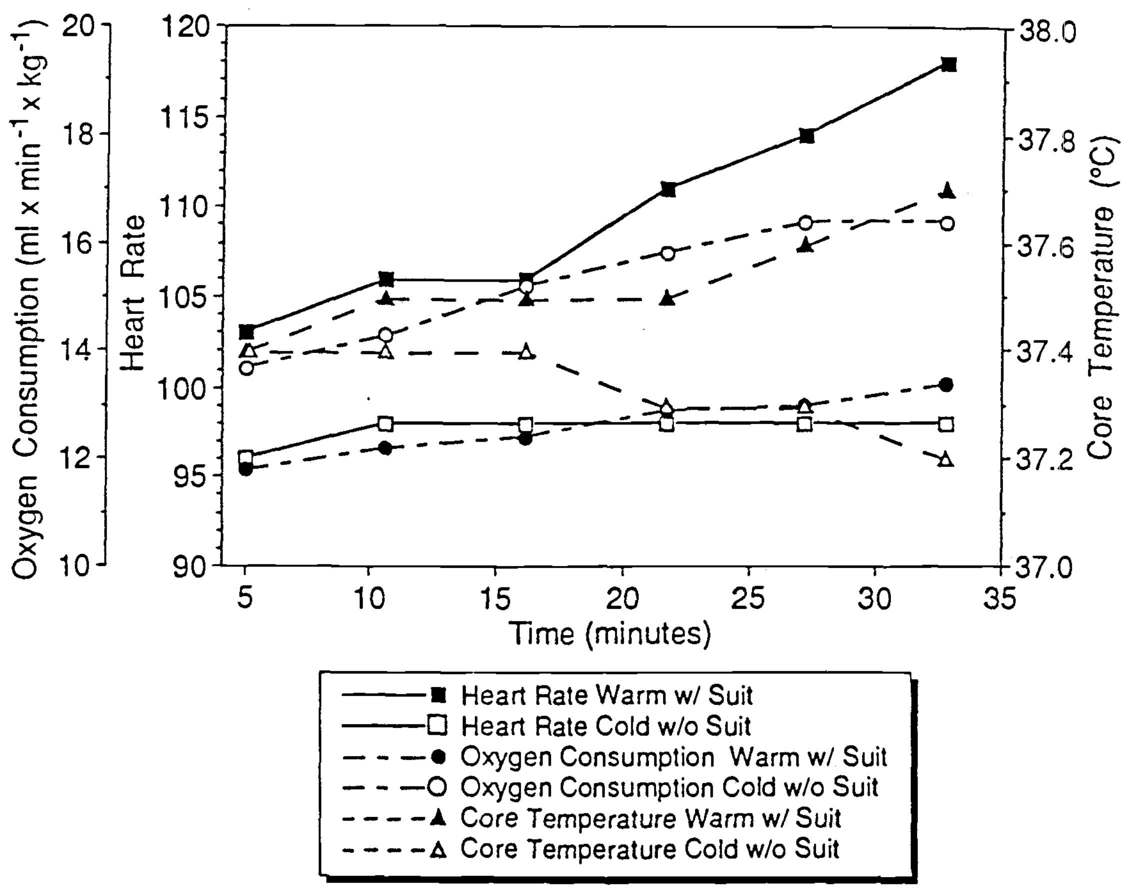

Figure 8. Heart rate, oxygen consumption, core temperature responses during warm water diving with suits and cold water diving without suits.

environment (warm water plus thermal protection) and/or the exercise intensity causes a rise in core temperature, the body will respond by trying to dissipate the excess heat. The increase in VO_2 observed in this study may then have been due to the additional heat load experienced under these conditions (Moore, Bernaver et al., 1970). The core temperature, in fact, increased from 37.4 °C to 37.7 °C (see Figure 9). Any increase in caloric requirements observed may have

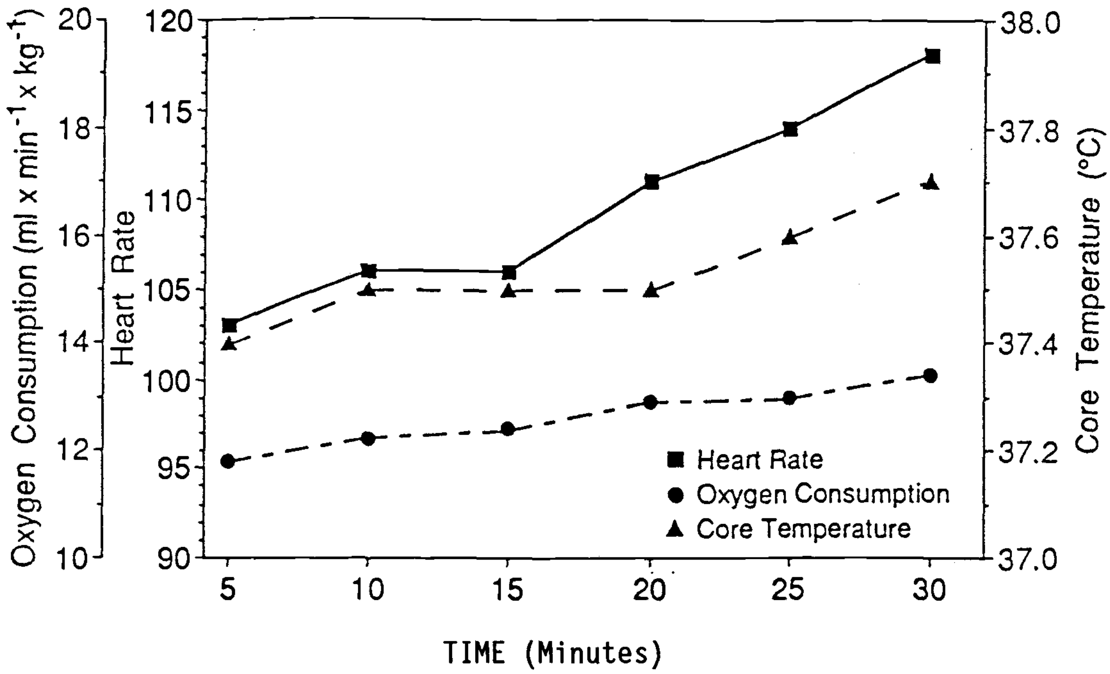

Figure 9. Heart rate, oxygen consumption and core temperature responses during warm water diving with suits.

been due to the increased circulation required to move the excess heat from the core to the periphery in an attempt to dissipate heat and maintain thermal balance. During this dive a rise in VO_2 and a fall in R.E.R. over time was observed. Calculations for caloric expenditure indicated that the rise in VO_2 was enough to elicit a small increase in caloric expenditure over time (from 4.7 k/cal to 5.5 k/cal per minute) despite the (small) decrease in R.E.R. It might be hypothesized, that as the divers produced excess heat, the body reacted by increasing peripheral vasodilation as a means to move the excess heat away from the core. The warm blood was diverted from the body's core to the shell. Humans can tolerate only relatively small variations in internal temperature. Consequently, exposure to heat stress initiates thermoregulatory mechanisms that dissipate heat at higher temperatures. If the increase in heat production occurs more rapidly than heat dissipation takes place one would expect to observe an increase in core temperature; this was in fact, what was observed. Also observed, was an increase in heart rate, oxygen consumption, and caloric expenditure during the thirty minute warm water dive with thermal protection.

Oxygen Consumption Responses During Normal Diving Conditions

Minutes six through 30 in warm water diving without suits produced higher VO_2 values than all six time periods in cold water with suits, although not significant. The results indicated a trend towards higher oxygen consumption values being elicited in warm water diving without suits when compared to cold water diving with suits. The results suggested that diving without a suit in warm water appeared to create more of a thermal stress for the divers than diving with a suit in the cold water. This suggestion was supported by the higher caloric expenditure, higher VO_2, and lower core temperatures observed during the warm water without suit dive when compared to the cold dive with suits.

Respiratory Exchange Ratio (R.E.R.)

Hypothesis 4

Statistical analysis resulted in the acceptance of the fourth hypothesis: there were significant differences found between respiratory exchange ratios during cold versus warm water diving with and without wet suits.

Significant treatment differences were evident at the (averaged) 5 minute intervals over the 30 minute test for the various diving conditions (warm with, warm without, cold with, and cold without).

The respiratory exchange ratio under each of the four experimental conditions over the 30 minute period of finning is presented in Figure 10. The standard error for respiratory exchange ratio was

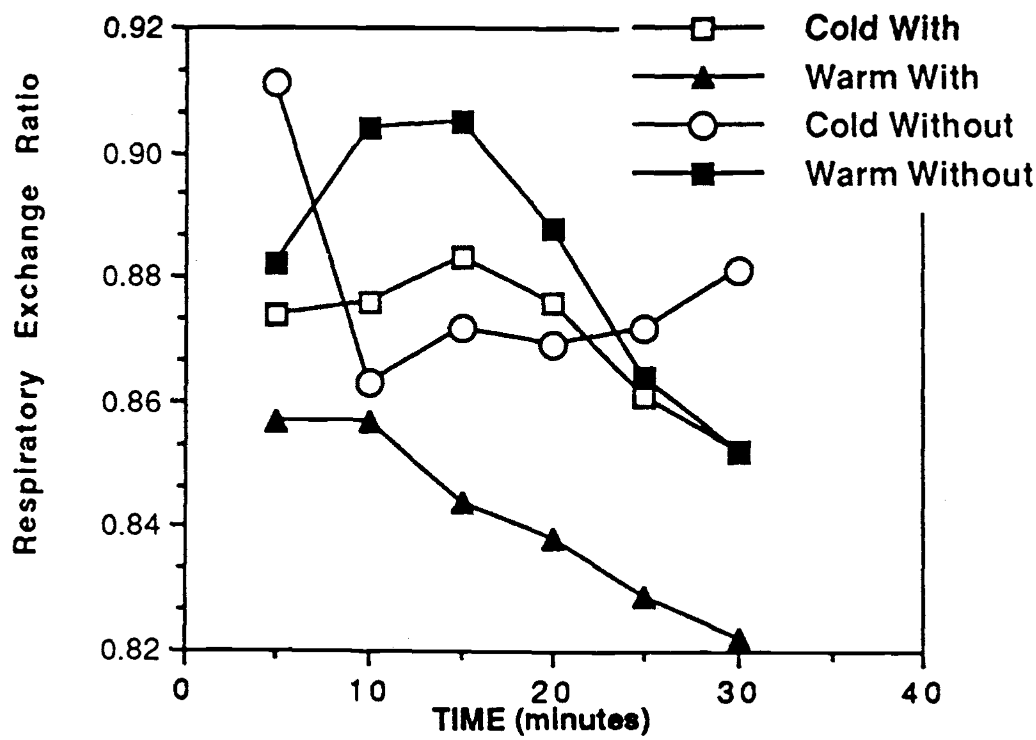

Figure 10. Respiratory exchange ratio responses during the four experimental conditions.

found to be 0.009 for all four conditions. The standard deviation for R.E.R. was found to be ±0.06 for the 29 °C water dive without suits, ±0.04 for the 29 °C water dive with suits, ±0.04 for the 18 °C water dive without suits, and $\pm.05$ for the 18 °C water dive with suits. The 24 respiratory exchange ratio mean and standard deviation values for the six time periods during the four diving conditions are found in Appendix K. There was a significant Three-Way interaction ($p < 0.0134$) found for suit x temperature x time. Again, the Newman-Keuls statistical procedure was used to determine where the specific significant interaction took place.

The R.E.R.s in all four diving conditions fluctuated despite the fact that the divers were working at a constant workload throughout the entire 30 minutes. The lowest individual R.E.R.s were found during warm water dives with wet suits, while the highest R.E.R.s were found during dives without wet suits in cold and warm water. The results indicated that higher R.E.R. values were elicited when diving in warm or cold water without suits.

The trend for R.E.R., over time, varies for each testing condition. Graphing indicated that for three of the dives (except cold water without suits) the lowest R.E.R.s were found towards the last portion of the 30 minutes. Conversely, the highest R.E.R.s were produced during the first five to ten minutes of diving. The results suggested that divers rely more on carbohydrates than fats as a fuel source at the start of each dive, yet, as time progressed they begin to rely less on carbohydrates and more on fat as a fuel source. The R.E.R. was significantly lower during minutes 11-30 in the warm dive with suits compared to minutes six-20 in the warm dive without suits and the first five minutes of the cold dive without suits.

Unlike the three dives just mentioned, the R.E.R. values for the cold water dive without suits increased (not significantly) during the thirty minutes of testing (ignoring the first five minute R.E.R. values because it may not represent a steady metabolic state due to apparent hyperventilation). The results suggested that under this condition divers relied less on carbohydrates and more on fats during the first portion of the dives and as time progressed they tended to rely more on carbohydrates and less on fats.

These higher R.E.R. values (noted towards the end of the dive), along with the high VO_2 values observed, support the hypothesis that cold water diving without suits required a higher caloric expenditure than the other three dives. However, these results are not supported by the literature. Timmons, Araujo et al., (1985) observed that fat utilization is enhanced by exercise in a cold environment. The cold stress dive apparently elicited a rise in R.E.R over time, indicating an enhancement of carbohydrate utilization during diving in cold environments. A possible explanation for this is presented in Chapter V.

Respiratory Exchange Ratio Responses During Warm Water Dive With Wet Suits

The lower values observed for warm water diving with thermal protection were between 0.85 and 0.82. These results indicate that diving in very warm conditions will elicit lower R.E.R. values compared to cold water conditions.

The results of this study have suggested that the warm water diving with thermal protection imposes a heat stress on the divers. McArdle, Katch et al., (1986) states that even when submaximal exercise is well tolerated in the heat, the work is generally accomplished with a greater dependence on anaerobic metabolism than in cooler conditions, which generally results in early fatigue. This suggests that as a diver's core temperature rises, he depends more on carbohydrates than fats as a fuel source. However, the results of this study (as stated above) suggest the opposite; as a diver's core temperature increased he depended more on fats than carbohydrates as a fuel source.

Respiratory Exchange Ratio During Normal Diving Conditions

The R.E.R. values observed during the cold water dive with suits were lower than the R.E.R.s during the warm water dive without suits although not significantly lower. The results suggested that diving with thermal protection in 18 °C water caused the diver to rely more on fats than carbohydrates as a fuel source when compared to warm water diving without thermal protection.

Caloric Expenditure

Caloric Expenditure Calculations

When the respiratory quotient is available (during steady state exercise), one can obtain an approximate caloric transformation as well as the percent contribution of fat and carbohydrate to the metabolic mixture. The kilocalories used during the entire 30 minute tests were calculated by taking the respiratory exchange ratio generated from the tests and finding the corresponding value for kilocalories used per liter of oxygen consumed using a nomogram (McArdle, Katch et at. 1986). This value was then multiplied by the volume of oxygen consumed per minute in liters to obtain the number of k/cals used per minute of diving.

<u>Caloric Expenditure Results</u>

The calculations for caloric expenditure (from R.E.R. & $\dot{V}O_2$ values) indicated that the highest level of caloric expenditure occurred during the cold water dive without wet suits. The results were not surprising. Although each of the other three dives required less caloric expenditure, it should be noted that the warm water dive without wet suits required slightly more k/cal per minute than did the cold water dive with suits. Diving without thermal protection, even in warm water, appeared to create a cold stress to the diver. This observation was supported by the increases in $\dot{V}O_2$ and $\dot{V}_E$ and the decreases in core temperature noted during both dives without suits. Had the warm water temperature been slightly colder, as is the case in some tropical diving areas, one would expect an even greater caloric expenditure from divers diving in these temperatures. Along these same lines, one can assume that caloric expenditure would also increase (despite the use of a full 1/4 " wet suit) if water temperature were much lower than the 18 °C employed during the cold dives.

The total number of k/cals required for diving in each of the four diving conditions was calculated. The average kilocalories used per minute during the 30 minute dive in cold water without wet suits was 6.22, the average used during the dive in cold water with wet suits was 5.05, while the average used during the two warm water dives was 5.24 (without suits), and 5.12 (with suits).

The results revealed that the "without suit" dives required a higher level of caloric expenditure when compared to the "with suit" dives. These results support the hypothesis presented earlier in this chapter. Cold water diving without suits required the highest level of caloric expenditure (6.22 k/cal per min.), and warm water diving required the next highest level of caloric expenditure (5.24 k/cal per min.) from a diver diving without a suit.

Caloric Expenditure During Cold Water Diving

The values identified above indicate that the highest level of caloric expenditure occurred while diving in 18 °C water without wet suits, the lowest occurred while diving in 18 °C water with wet suits. These observations indicated that the greater the cold stress, the higher the caloric expenditure; which is what one would expect. It appeared that diving in the 18 °C temperature with thermal protection did not require as much caloric expenditure as any of the other three diving conditions. These results indicated that the thermal protection added to the diver does in fact protect the diver from cold stress that would normally be imposed during diving in 18 °C water. These observations are corroborated by the $\dot{V}O_2$, $\dot{V}_E$, and core temperature values noted for the cold water dives (see Figures 11 and 12).

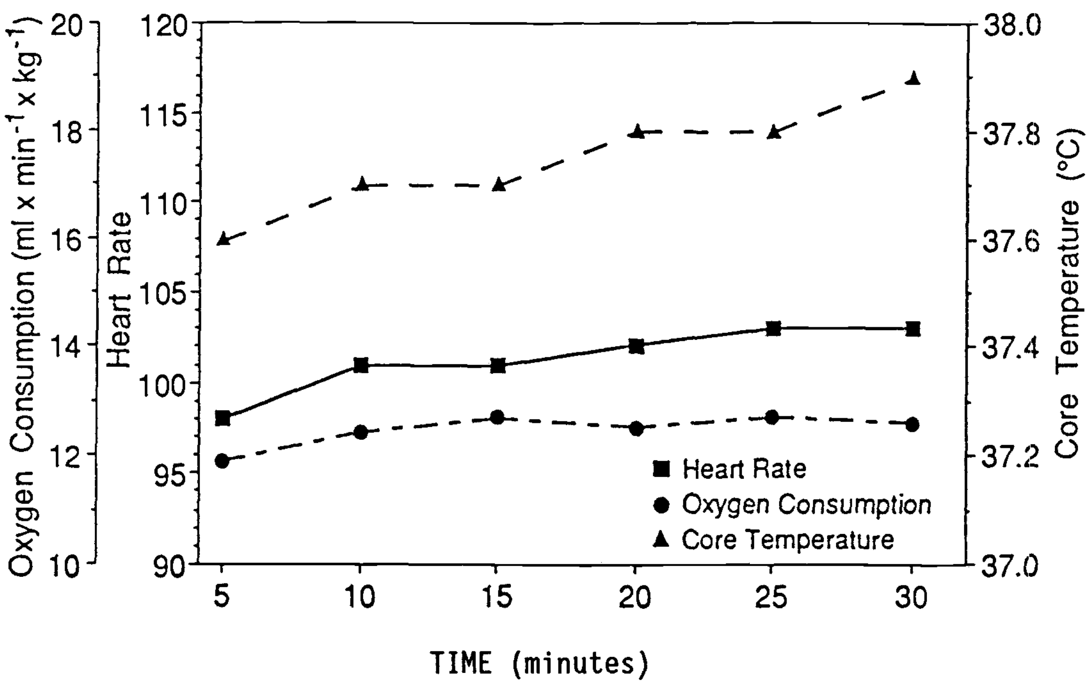

Figure 11. Heart rate, oxygen consumption, and core temperature responses during cold water diving with suits.

Caloric Expenditure During Warm Water Diving

The results for caloric expenditure, given above, indicate that diving in warm water without thermal protection required a higher level of caloric expenditure than diving with thermal protection in either warm or cold water. The interesting point to note is that diving in warm water without wet suits required a higher level of caloric expenditure than does diving in cold water with thermal protection. When comparing the two normal diving conditions one can

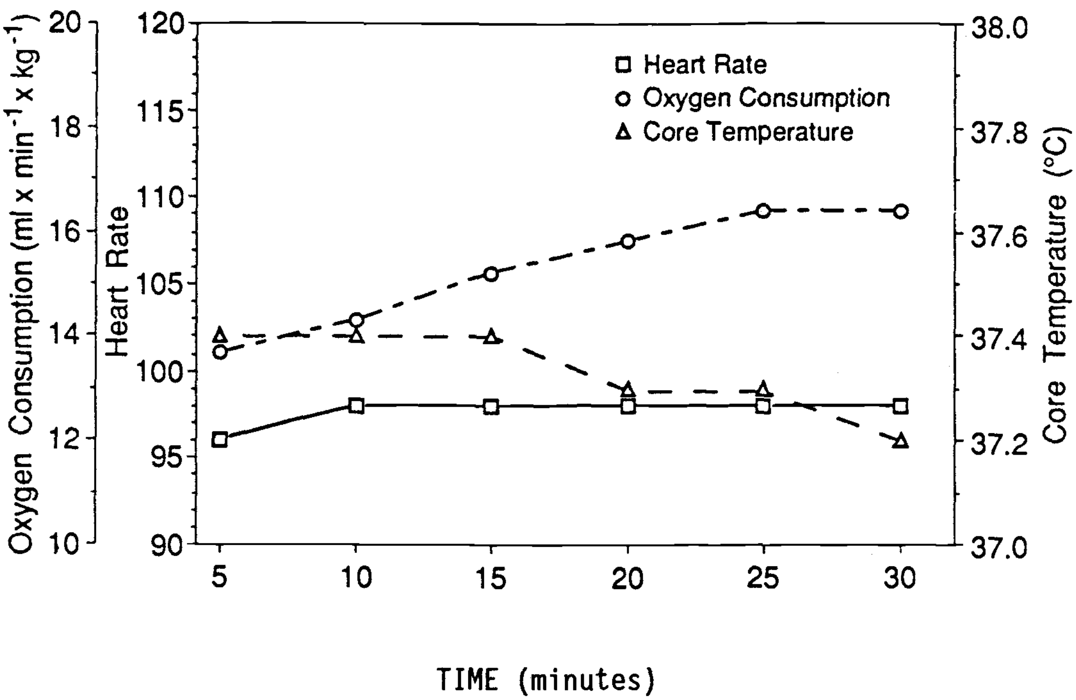

Figure 12. Heart rate, oxygen consumption, and core temperature responses during cold water diving without suits.

deduce that divers were subjected to more cold stress when unprotected by suits in warm water than if they were to dive with suits in water which is 18 °C or warmer. Since cold stress appeared to increase caloric expenditure and VO_2, one might hypothesize that had the water temperature during the cold water dive been several degrees colder, one may have observed some cold stress responses even with the thermal insulation provided by the wet suit.

In summary, the cold water dive without suits apparently required a higher level of caloric expenditure than the other three dives. These results were expected because the cold water dive without suits would create a much greater cold stress to the diver and require a higher caloric expenditure and higher VO_2 than any of the other three dives. The warm water dive without thermal protection required the next highest level of caloric expenditure when compared to the remaining two dives. Thus, even in warm water without wet suit protection a cold stress is imposed requiring a slightly higher caloric expenditure and higher oxygen consumption.

Total k/cals Used During Each of The Diving Conditions

To obtain the total number of k/cal used during the entire 30 minutes for each test, the average number of calories used per minute was multiplied by 30. The total number of calories used during the dive in cold water without wet suits was 186.6. The dive in cold water with wet suits used 151.5 k/cals, while the warm water dive without wet suits required 157.2 k/cals. The warm water dive with thermal protection used 153.6 k/cals.

These results are in agreement with those presented for caloric expenditure per minute. The results for caloric expenditure support the hypothesis that warm water diving without suits induces a cold stress despite the divers' subjective feelings of comfort.

Had dive time been extended during either of the cold stress dives, one would expect to see caloric expenditure increase at a faster rate as time progressed.

Caloric expenditure observed during finning at the surface may not give a good indication of the true caloric expenditure while diving at depth. While wearing a wet suit, one would expect to observe a higher caloric expenditure because as a diver descends, his or her wet suit becomes compressed and the thermal protection it provides decreases very quickly. With less thermal protection divers become chilled at a much faster rate, core temperature drops, causing an increase in caloric expenditure, and a rise in oxygen consumption. For example, diving to approximately 30 feet compresses a wet suit to one half its original thickness. With this change in the protective suit, cold stress would pose a greater threat to the diver.

Heart Rate (H.R., Beats per Minute)

Hypothesis 6

Statistical analysis resulted in the acceptance of the fifth hypothesis: there were significant differences found between heart rates during cold versus warm water diving with and without wet suits.

Significant treatment differences were evident at the (averaged) 5 minute intervals over the 30 minute test for the various diving conditions (warm with, warm without, cold with, and cold without).

Heart rates under each of the four experimental conditions over the 30 minute period of finning are presented in Figure 13. The standard error for heart rate was found to be 0.86 (bpm) for all four dives. The standard deviation for H.R. was found to be ±12.3 for the 29 °C water dive without suits, ±13.4 for the 29 °C water dive with suits, the 18 °C dive without suits and for the 18 °C water dive with suits. The 24 mean heart rates and standard deviations for the six time periods, during the four diving conditions are found in Appendix L. There was a significant interaction ($p < 0.0017$) found for suit x temperature x time. Therefore the Newman-Keuls statistical procedure was used to determine where the specific significant interaction took place.

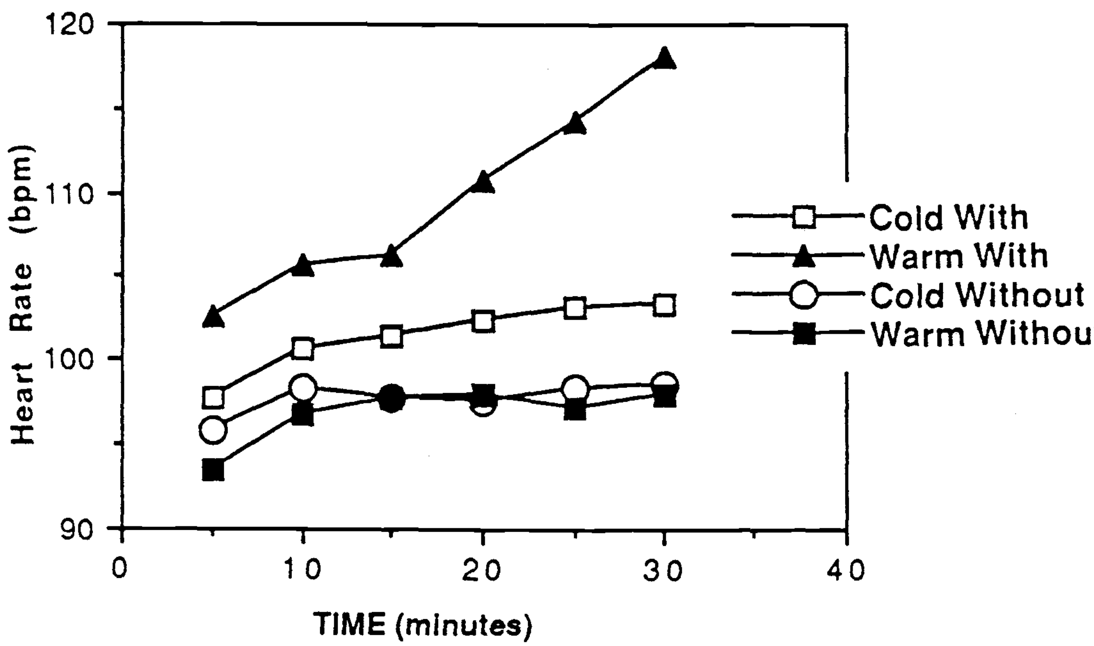

Figure 13. Heat rate responses during the four diving conditions.

The highest mean heart rate (117.9) was achieved during the last five minutes of testing in warm water while wearing suits, while the lowest mean heart rate (93.5) was produced during the first five minutes of testing in warm water without suits. The six highest mean H.R.s were all produced in warm water with thermal protection while the six lowest mean H.R.s were found in warm water without suits (four) and in cold water without suits (two).

Two of the four diving conditions showed a trend towards an increase (a significant increase was observed during both warm water dives) in H.R. over time, despite the fact that divers were finning at a fixed workload. The two dives without suits showed more of a plateau of H.R.s across time. The discussion of these results follows.

Heart Rate Responses During Diving With Wet Suits

There was a significant difference between all 30 minutes during the warm water dive with wet suits (H.R.: 102.6-117.9) and all other dives except minutes 6 through 30 in the cold water dive with suits (H.R.: 98.2-103.4). These results substantiated diver's communications to the researchers during testing. Many of the divers indicated with hand signals that they were uncomfortably warm while diving with suits in the warm water. This heat stress appeared to have elicited an increase in heart rate as a means of dissipating excess heat from the body. The cold water dive with suits also created an environment that was a heat stress for the divers. Most likely, the divers physiologically responded to the heat stress with an increase in heart rate to assist in heat dissipation. The assumption that diving "with suits" imposed a heat stress and increased H.R. was corroborated by the data noted for $\dot{V}O_2$ and core temperature. However, the "heat stress dives" did not elicit higher $\dot{V}O_2$ values when compared to values observed during "cold stress dives".

Heart Rate Responses During Normal Diving Conditions

All the cold water dive times with suits (except the first five minutes), produced significantly higher heart rates than observed during the 30 minutes of diving in warm water without suits.

One explanation might be that the suit offered more than adequate thermal protection for the divers, hence they may have been heat stressed to some extent (in the cold water). This explanation appeared to be supported by the lower caloric expenditure, higher core temperatures, and lower oxygen consumption values observed during this dive as compared to the warm water without suits dive (Figure 14). On the other hand, diving in warm water without suits for thirty minutes appeared to produce a cold stress. This may have caused portions of the circulatory system to vaso-venoconstrict and the heart rate to slow down, as expected in cold environments. This postulation was supported by the higher caloric expenditure, lower core temperatures, and higher oxygen consumption values observed during this dive, as compared to the cold water dive with suits.

In general the lower heart rates were observed during the dives (warm and cold) without wet suits, and the higher heart rates during the dives (warm and cold) with wet suits. One might hypothesize that cold stress lowers heart rates while heat stress increases heart rates. It also might be postulated that the divers responded to the

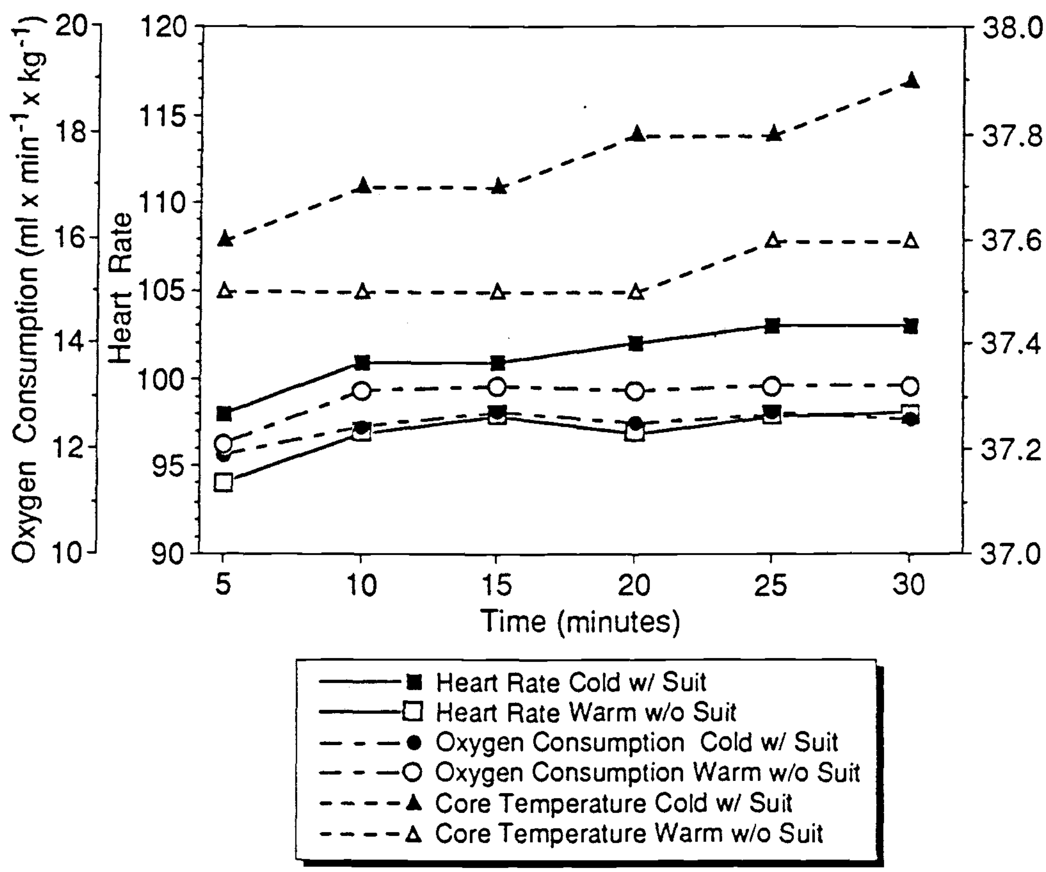

Figure 14. Heart rate, oxygen consumption, and core temperature responses during "normal" diving conditions.

cold stress by effecting peripheral vasoconstriction thus increasing central blood volumes and a concomitant slowing of the heart rate. Heat stress caused peripheral vasodilation and a resultant decrease in central blood volume, requiring an increase in the heart rate.

Temperature (T °C)

Hypothesis 7

Statistical analysis resulted in the acceptance of the sixth hypothesis: there were significant differences found between core temperatures (T°C) during cold versus warm water diving with and without wet suits.

Significant treatment differences were evident at the (averaged) 5 minute intervals over the 30 minute test for the various diving conditions (warm with, warm without, cold with, and cold without).

The core temperature under each of the four experimental conditions over the 30 minute period of finning is presented in Figure 15. The standard error for core temperature was found to be 0.024 °C for all four dives. The standard deviation for core temperature was found to be ±0.48 for the 29 °C dive without suits, ±0.39 for the 29 °C water dive with suits, ±1.1 for the 18 °C dive without suits, and ±0.38 for the 18 °C with suits. The 24 mean core temperatures and standard deviations for the six time periods during each of the four diving conditions are found in Appendix M. There was a significant interaction ($p < 0.0000$) found for suit x temperature x time. Again the Newman-Keuls statistical procedure was used to determine where the specific significant interaction took place.

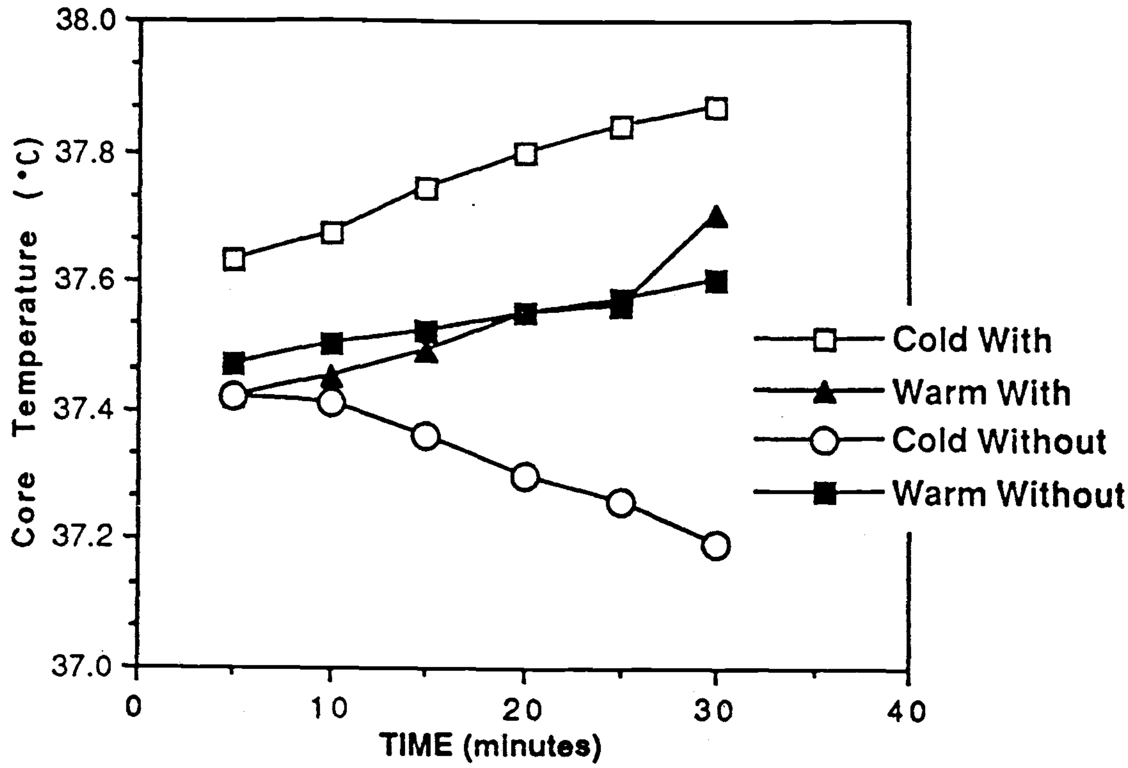

Figure 15. Core temperature responses during the four diving conditions.

Core Temperature Responses During Cold Water Diving Without Suits

Trends seen for diving in the cold water without suits over time showed a gradual decrease in core temperature from 37.42 to 37.19 °C. Significant decreases were found between each time period throughout the cold water dive without suits. Diving in 18 °C water without thermal protection appeared to create a cold stress which increased heat loss from the divers. The leaner divers responded late in the test by shivering violently. The divers that appeared to be least affected by the cold environment (showed no signs of shivering), were those divers with the highest percent of body fat, and the two divers with the most cold water experiences.

The core temperatures elicited during the entire 30 minutes of diving in the cold water without suits were significantly lower than all times and dives except the first 15 minutes in warm water with suits, and warm water without suits.

Core Temperature Responses During Warm Water Diving With Suits

Core temperature gradually increased from 37.42 to 37.70 °C during the thirty minutes of diving in warm water with suits. The core temperature during the last fifteen minutes of finning was significantly higher than the first five minutes, and the last five minutes of finning was significantly higher than the first ten minutes. These results, again, support the subjective reports made by the divers; that many were very warm during this particular dive. Divers responded physiologically to the heat stress with an increase in core temperature because their systems dissipated excess heat at a slower rate than it was being produced. Some of the divers reported that they were sweating during this dive, and felt sweat dripping down their faces, on the inside of the mask. The diver with the highest percent body fat, actually terminated the warm water dive (with a suit) early due to "perception of heat stress". His final core temperature was noted at 37.8 °C.

Core Temperature Responses During Normal Diving Conditions

Core temperature gradually increased from 37.63 to 37.87 °C during the thirty minute dive in cold water with suits, and also gradually increased from 37.47 to 37.60 °C during the warm water dive without suits. The results indicated a trend towards a small, yet, significant increase in core temperature (37.5 °C to 37.6 °C) in warm water diving without suits from the first 5 minutes to the last five minutes. These results are somewhat difficult to interpret. Either the dive conditions posed a metabolic heat load (which was suggested by the small (0.1 °C) rise in core temperature), or more likely they had been cold stressed. If this second hypothesis were true, one might assume that the rise in core temperature occurred as a consequence of vasoconstriction at the body's extremities as a means of conserving heat in the face of a heat loss. The data on oxygen consumption, heart rate, and energy expenditure support the latter hypothesis. Assuming that the divers are under a small cold stress, one might expect to see the core temperature eventually drop during the warm dive without suits during extended dives (see Figures 16 and 17).

Observations of core temperature during the cold water dives with suits also indicated a significant increase from the start of the test until the 30 minute termination time. The mean core temperature during the last fifteen minutes was found to be significantly higher than the first ten minutes of testing. There was also a significant

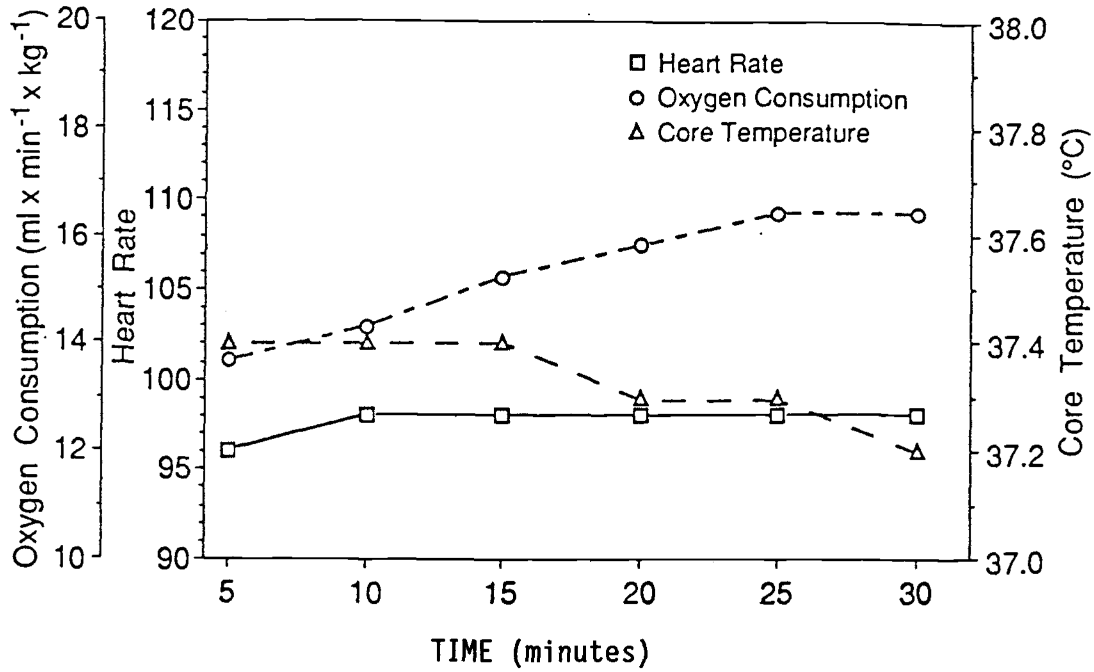

Figure 16. Heart rate, oxygen consumption, and core temperature responses during cold water diving without suits.

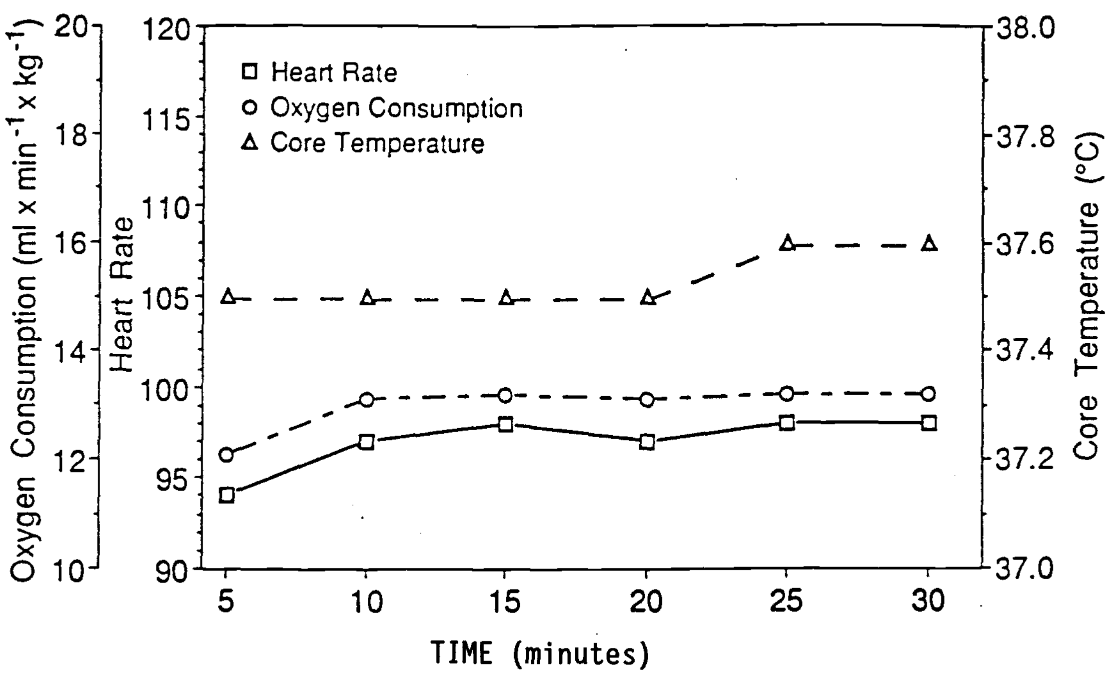

Figure 17. Heart rate, oxygen consumption, and core temperature responses during warm water diving without suits.

increase in core temperature between minutes eleven through fifteen and again between minutes 21-30 of the test. These results, along with those for caloric expenditure, oxygen consumption and heart rate, support the hypothesis that diving with thermal protection in water as cold as 18 °C did not pose a cold stress to the diver. Most divers reported subjective feelings of being "very comfortable" during this dive. It appeared that the full 1/4" wet suit provided more than adequate thermal protection to the diver in 18 °C water.

The first 15 minutes of diving in warm water without suits elicited significantly lower core temperatures than all of the 30 minutes core temperature values during the cold dive with suits. Also the last 15 minutes of diving in warm water without suits elicited significantly lower core temperatures than the last 20 minutes of diving in cold water with suits.

Core temperature responses to diving would most likely be quite different if: the water temperatures had been warmer or colder, the diver had been diving at greater depths, the workload had been larger or smaller, or if the dive time had been extended. Any of these changes in diving conditions would alter the responses, not only for core temperature but also for the other dependent variables.

Body Percent Fat as a Covariate Factor

The four way ANOVA (see Tables II and III) revealed that the covariate, percent body fat, significantly influenced oxygen consumption expressed in absolute terms, ($\dot{V}O_2$ L x min^{-1}) relative terms

($\dot{V}O_2$ ml x min^{-1} x kg^{-1}). The mean percent body fat for all fifteen divers was 22.4%. The standard deviation was 4.02 for all 15 divers.

Table II. Main Effects and Interaction for Dependent Variables

	$\dot{V}_E$ Lxmin^{-1}	$\dot{V}O_2$ Lxmin^{-1}	$\dot{V}O_2$ mlxkg^{-1}xmin^{-1}	RER	HR	BF	T°C
1) % B.Fat	.0019	.0157	.0006	.0079	-----	-----	-----
2) Suit	.0052	.0084	.0071	----	.0000	.0099	-----
3) Temp.	.0005	.0106	.0192	----	.0390	.0501	.0018
4) T x S	.0054	.0081	.0075	----	.0271	.0204	.0019
5) Time	----	.0000	.0000	.0041	.0000	.0067	.0135
6) Time x S	----	----	----	----	.0000	.0366	.0000
7) Time x T	.0127	----	----	----	.0003	----	.0010
8) Time xTxS	.0075	.0000	.0000	.0134	.0017	----	.0000

This table presents the main effects and interaction for each of the dependent variables with respect to: 1) percent body fat, 2) suit (with & without), 3) temperature (cold and warm), 4) interaction of suit and temperature, 5) time (30 minutes, 6 five minute averages), 6) interaction of time and suit, 7) interaction of time and temperature, 8) and interaction of temperature (T) x suit (S) x time (MIN) .

<u>Relationship of Body Composition to Oxygen Consumption Responses (L x min^{-1})</u>

There was a significant relationship ($p < 0.0517$) found between body composition, the four diving conditions, and the dependent variable oxygen consumption ($\dot{V}O_2$). For each 1% change in body fat (from the mean of 22.4%) there was a 0.015 L x min^{-1} change in $\dot{V}O_2$. Thus, for each 1% increase in body fat above the mean of 22.4% there was a decrease in $\dot{V}O_2$ by 0.015 L x min^{-1}. Conversely for each 1% decrease in body fat below the mean of 22.4% one should expect an increase in $\dot{V}O_2$ by .015 L x min^{-1}. These results suggested that the leaner a diver (under each of the four experimental diving conditions) the higher the $\dot{V}O_2$ expected during a fixed workload. The fatter a diver was (under each of the four experimental diving conditions) the lower the $\dot{V}O_2$ expected during a fixed workload.

Table III. Sum of Squares, Degrees of Freedom, Mean Square, Mean Square Error, F Value, and Probability (P)

	SOURCE	SUM OF SQUARES	D.F.	MEAN SQUARE	F	TAIL PROB.
B.F. (bpm)	STM	49.81170	5	9.96234	2.56	0.0366
	ERROR	233.85538	60			
Min Vent. ($L \times min^{-1}$)	STM	89.33874	5	17.86775	3.52	0.0075
	ERROR	304.92290	60	5.08205		
$\dot{V}O_2$ ($L \times min^{-1}$)	STM	0.19537	5	0.03907	10.28	0.0000
	ERROR	0.22806	60	0.00380		
$\dot{V}O_2$ ($ml \times min^{-1} \times kg^{-1}$)	STM	24.40435	5	4.88087	7.89	0.0000
	ERROR	37.13860	60	0.61898		
R.E.R.	STM	0.01968	5	0.00394	3.16	0.0134
	ERROR	0.07471	60	0.00125		
H.R.(b/min)	STM	244.39993	5	48.87999	4.44	0.0017
	ERROR	661.04014	60	11.01734		
T °C	STM	0.31137	5	0.06227	7.01	0.0000
	ERROR	0.53320	60	0.00889		

Source of Variance, Sum of Squares, Degrees of Freedom, Mean Square and Mean Square Error, F value, and Tail probability for the following variables for all dives with and without suits in warm and cold water.

This information appears to be more important when considering diving in cold environments. Differences in body composition between individuals has a significant effect on physiologic function in the cold, both at rest and during exercise. In cold water, excess subcutaneous fat can be advantageous, either during rest or exercise. The excess fat increases a person effective insulation when peripheral blood is redirected to the body's core in cold water. For leaner swimmers, however, heat generated in exercise is insufficient to counter the heat lost to the water and, as such, the core temperature drops as the body cools (Burton & Edholm, 1955). The physiologic strain imposed by the cold stress depends on the environmental temperature, the level of metabolism and the resistance to heat flow provided by body fat. A fat person who is comfortable resting in 26 °C water may actually sweat during intense exercise. This same person may find 18 °C more comfortable when exercising intensely. The lean person however, will find the 18 °C debilitating both during exercise and at rest (McArdle, Katch et al., 1986, Keatinge, 1960). If the diver remains warm due to added thermal protection he will require a lower expenditure of energy and consume less oxygen (VO_2).

On the other hand fatness is a liability when working in the heat. Because the specific heat of fat is greater than that of muscle tissue, excess fat increases the insulatory quality of the body shell and retards conduction of heat to the periphery. Therefore fat divers diving in warm diving environments would have greater trouble maintaining thermal balance than leaner divers (Keatinge, 1960). Although this would suggest an increased metabolic rate and oxygen consumption for the fatter divers, the statistical analysis indicated that fatter divers consumed less oxygen than leaner divers.

Relationship of Body Composition to Oxygen Consumption (ml x min^{-1} x kg^{-1})

There was a significant relationship ($p < 0.0006$) found between body composition and the dependent variable oxygen consumption ($\dot{V}O_2$ ml x min^{-1} x kg^{-1}). It was found that for each 1% change in body fat (from the mean of 22.4%) there was a 0.31 ml x min^{-1} x kg^{-1} change in $\dot{V}O_2$. Thus for each 1% increase in body fat above the mean of 22.4% there was a decrease in $\dot{V}O_2$ by 0.31 ml x min^{-1} x kg^{-1}. Conversely, for each 1% decrease in body fat below the mean of 22.4% an increase in $\dot{V}O_2$ by 0.31 ml x min^{-1} x kg^{-1} should be expected. The results suggested that the leaner a diver was, (under the four experimental diving conditions) the higher the $\dot{V}O_2$ expected during a fixed workload. Conversely, the fatter a diver was, (under the four experimental diving conditions), the lower the expected $\dot{V}O_2$ during a fixed sub-maximal finning session. The implications for these results are the same as those presented above for $\dot{V}O_2$ L x min^{-1}. It appeared that divers with higher percentages of body fat consumed less oxygen and expended less calories during diving, when compared to leaner divers under the conditions of this study.

Summary

Statistical analysis resulted in the acceptance of all seven hypotheses. The premise that breathing frequency, minute ventilation, oxygen consumption, respiratory exchange ratio, caloric expenditure, heart rate, and core temperature responses are different while diving in cold and warm water with and without wet suits has been supported. Further discussion of these results follows in the next section.

CHAPTER V

DISCUSSION, CONSIDERATIONS, CONCLUSIONS, SUMMARY

This investigation was conducted to simulate, as close as possible, normal recreational diving conditions to determine if physiological differences exist between warm and cold water diving with and without thermal protection.

Investigators have focused much attention on respiratory responses, cardiovascular responses, and caloric expenditure in runners and cyclers, however, there has been very little research conducted on scuba divers during submerged finning. There is even less information on how each of these variables may play a role in altering the safety of a diver's diving experiences.

The purpose of this study was to determine if, and to what extent, different diving environments affect a diver's cardiovascular, respiratory and metabolic responses. The researcher hypothesized that scuba divers would display significantly different breathing frequencies, minute ventilations, oxygen consumptions, respiratory exchange ratios, heart rates, and core temperatures during thirty minutes of submerged finning in two different water temperatures with and without thermal protection.

The subjects were fifteen male certified scuba divers ranging in age from 33 to 50 years. They were subjected to four different diving conditions for a maximum of 30 minutes. They finned at a workload of 35% of their previously determined maximum workload. During the 30 minutes, measures for breathing frequency, minute ventilation, oxygen consumption, respiratory exchange ratio, heart rate, and core temperature, were gathered. Caloric expenditure was calculated from respiratory exchange ratio and oxygen consumption values. Any observable differences found (especially between the two normal diving conditions; warm without suits and cold with suits) would suggest a need for this information to be shared with the recreational diving population along with other interest groups for purposes of enhancing diving education and improving diving safety.

This particular study examined differences in breathing frequency (bpm), minute ventilation (L x min^{-1}), absolute oxygen consumption (L x min^{-1}), relative oxygen consumption (ml x min^{-1} x Kg^{-1}), respiratory exchange ratio, heart rate (bpm), and core temperature (°C), in four distinct diving conditions.

Discussion

Breathing Frequency and Minute Ventilation

Breathing Frequency Response. There were significant differences found between breathing frequency (breaths per minute) during cold versus warm water diving with and without wet suits.

The results of this particular study indicate that diving without suits when compared to diving with suits, produced significantly lower breathing frequencies during most dive times. Research relevant to this issue could not be located. The author can only hypothesize then as to why diving without wet suits, regardless of the water temperature, resulted in the divers breathing frequency being lower than when they dove with suits. The hypothesis presented in Chapter IV suggested that the addition of the 1/4 " foamed neoprene wet suit posed an added restriction to the divers' ability to breathe normally. The diver reacted to the decrease in chest wall expansion and tidal volume by taking smaller more frequent breaths to meet the specific demands of the exercise intensity and diving environment. A study conducted by Costill, Cahill et al. (1967) observed swimmers swimming at a submaximal intensity, in three different water temperatures. The results indicated that breathing frequencies were not found to be statistically different, even though subjects respired more often in the coldest water temperature. The results of Costill and co-workers study along with those of this scuba study would support the hypothesis that the breathing frequency values observed were influenced by the use of wet suits.

Minute Ventilation Response. There were significant differences found between minute ventilation ($L \times min^{-1}$) during cold versus warm water diving with and without wet suits.

There were numerous significant differences found between the five minute averages during the various dives. The results indicated small standard deviations, which enhanced the potential for significant differences. The $\dot{V}_E$ values (all time periods) for the cold water dive without suits were significantly higher than most other time periods within the other dive conditions regardless of time, temperature, or suit use. The only exceptions to this were found during minutes 6 through 25 in warm water diving without suits, and the last five minutes of diving in warm water with suits. The majority of the lowest minute ventilation values were observed during the warm and cold water dives with suits. The $\dot{V}_E$ values for these dives were significantly lower than those observed during the cold water dive without suits but not the warm water dive without suits. Costill, Cahill et al., (1967) reported that the $\dot{V}_E$ and $\dot{V}O_2$ were not statistically different between three water temperatures (17.4 °C, $\dot{V}_E$ = 60.5 L x min^{-1}, $\dot{V}O_2$ = 3.0 L x min^{-1}); (26.8 °C, $\dot{V}_E$ = 53.2 L x min^{-1}, $\dot{V}O_2$ = 2.9 L x min^{-1}); and (33.1 °C, $\dot{V}_E$ = 55.8 L x min^{-1}, $\dot{V}O_2$ = 2.8 L x min^{-1}). These results contradict the results of this scuba study. One possible reason for this might be that the submaximal (self determined, intensity not indicated) work load employed during Costill's study was greater than the 35% max load employed in this scuba study. If the workload in Costill's study was more intense, then the swimmers may have been less affected by the colder water temperatures because they generated more heat while swimming than the divers did while finning. The mode of the exercise might also have affected the results. The swimmers used arm and leg movements (breast stroke), while the divers used only their legs, therefore, less muscle mass was utilized for propulsion during diving than during swimming. The $\dot{V}_E$ in the coldest water temperature (17.4 °C) increased during the first half of the 20 minute test then decreased during the second half of the test. During the warm water test (33.1 °C) the $\dot{V}_E$ increased steadily throughout the test, while $\dot{V}_E$ decreased steadily throughout the medium water temperature (26.8 °C) test. Oxygen consumption increased during the first ten minutes in 33.1 °C, then decreased the last ten minutes, while a plateau in $\dot{V}O_2$ was observed during the two other water temperatures. Based on these results, one might hypothesize that the shorter time period (20 min.) for swimming did not allow for greater cardiovascular, respiratory, or metabolic changes to occur over time.

Ventilation Responses During Normal Diving Conditions. Diving in warm water without wet suits resulted in a slightly higher $\dot{V}_E$ than diving in cold water with wet suits. Although not significant, there was a definite trend towards higher $\dot{V}_E$ responses during warm water without suit diving. If dive time had been extended, one might speculate that divers who do not wear thermal protection in warm water to have higher minute ventilation values than if they were to dive with thermal protection in water as cold as 18 °C. The normal relationship between increases in $\dot{V}_E$ and increases in metabolic requirements was supported by the data noted during this test. The results indicated that warm water diving without suits required more caloric expenditure, higher $\dot{V}O_2$, and higher $\dot{V}_E$ responses than the cold dive with suits.

Relationship of Ventilation and Breathing Frequency Responses. Diving without suits in cold water produced a significantly lower breathing frequency, and (in part) a significantly higher minute ventilation when compared to the other three dives. Conversely, it was found that diving with suits elicited significantly higher breathing frequency values and generally lower minute ventilation values (significant only when compared to the cold dive without suits). None of the divers complained of having difficulty breathing during any of the tests, in fact most felt very comfortable with the breathing apparatus. One might assume that as wet suit restriction decreased normal chest wall expansion, divers compensated by increasing breathing frequency in order to achieve the minute ventilation required to meet the increased metabolic demands of the body. The data revealed that as $\dot{V}O_2$ and caloric expenditure increased, $\dot{V}_E$ also increased.

Oxygen Consumption ($\dot{V}O_2$, $L \times min^{-1}$)

There were significant differences found between oxygen consumption during cold versus warm water diving with and without wet suits.

There was a significant increase ($P < 0.0000$) in $\dot{V}O_2$ while finning for 30 minutes during three of the four experimental dives. This suggested that the length of time spent in the water, and/or the diving environment, significantly increased a divers oxygen consumption. Specifically there was a 6% (non significant) increase in $\dot{V}O_2$ during the cold water dive with suits, an 8% significant increase during the warm water dive with suits, and a 21% (significant) and 10%

(significant) increase in $\dot{V}O_2$ during the cold and warm dives, respectively, without suits. The cold water dive without suits (minutes six through 30) produced significantly higher $\dot{V}O_2$ values than all other dives regardless of time, temperature, or suit use. The results also indicated that although not statistically significant, in most cases, (11 out of 12) the highest $\dot{V}O_2$ values were produced during the dive without wet suits, while 11 of the lowest $\dot{V}O_2$ values were observed during dives with wet suits. Diving without suits in either warm or cold water appeared to place the diver under a relative cold stress which required a higher caloric expenditure. Decreases in core temperature elicit increases in the metabolic demand, due in part, to shivering. This increase in metabolic demand is then achieved by increases in $\dot{V}O_2$, and $\dot{V}_E$.

Oxygen Consumption Responses During Normal Diving Conditions

When comparing the warm water dive without suits to the cold dive with suits, only the first five minutes of diving in cold water with suits produced a significantly lower $\dot{V}O_2$ value than all other time periods in warm water without suits. Studies cited in Chapter II and V (Craig, & Dvorak, 1968, Donald, & Davidson, 1954) indicate that cold water exposure produces higher $\dot{V}O_2$ values than warm water exposure because of the higher caloric expenditure required by the body as it attempts to maintain normal core temperatures in the face of heat loss in the cold environment. The literature that suggests cold water exposure produces higher $\dot{V}O_2$ values than warm water exposure refers to subjects who are immersed with no thermal protective clothing. Obviously, if thermal protection is provided to the subject, then the heat lost to a cold water environment would be less than the amount lost without thermal protection. This particular study revealed that the cold water environment did not elicit the expected higher $\dot{V}O_2$ values than the warm water environment, but only because the subjects were thermally protected from the cold by 1/4 inch wet suits. Therefore, it is the total diving environment, not just the temperature of the water which is reflected in the $\dot{V}O_2$ values observed in this study. Diving in cold water (18 °C) with a wet suit provides thermal protection and prevents heat from being lost from the body as quickly as it is lost while diving in warm water without a suit. The smaller the heat loss from the body, the less caloric expenditure is needed to maintain thermal balance. The lower caloric expenditure was reflected in the lower $\dot{V}O_2$ and $\dot{V}_E$ values observed during the cold dive with thermal protection. With this in mind one might hypothesize that diving without suits (even in warm water) required a higher level of caloric expenditure by the body, in it's attempt to maintain thermal balance. The increase in caloric expenditure, (during the warm dive without suits) is reflected in the observed increase in $\dot{V}O_2$ and $\dot{V}_E$. If warm water diving without thermal protection does create a cold stress for the diver, one might expect to see even greater increases in oxygen consumption (over time) if the divers were to dive for extended periods of time, and/or if they were to participate in several dives during one day. Usually participation in several dives in one day will cause a slow but gradual loss of body heat (lowering of core temperature) which would result in an increased metabolic demand as the body attempts to maintain thermal balance (Shilling, Carlston et al., 1983). This increase in energy expenditure would be reflected in the rise in oxygen consumption (L x min^{-1}) as was observed.

Oxygen Consumption Results ($\dot{V}O_2$ ml x min^{-1})

There were significant differences found between oxygen consumption during cold versus warm water diving with and without wet suits.

The results for relative $\dot{V}O_2$ were similar to those found for absolute $\dot{V}O_2$. This study revealed a significant increase in $\dot{V}O_2$ for three of four (all except the cold dive with suits) experimental dives during the 30 minutes. The cold water dive without suits elicited significantly higher $\dot{V}O_2$ values than all other dives with only a few exceptions. During this dive there was an 18% increase in $\dot{V}O_2$. There was no significant difference in $\dot{V}O_2$ found between the remaining three dives, however there were definite trends observed. The warm water dive without suits elicited the second highest $\dot{V}O_2$ values, the cold water dive with suits elicited the third highest $\dot{V}O_2$ values, while the warm water dive with suits elicited the lowest $\dot{V}O_2$ values.

When comparing normal diving conditions the results indicate that oxygen consumption is greater in warm water (29 °C) diving without suits than cold water (18 °C) diving with suits, although not significantly greater.

Cold exposure has been reported to elicit higher $\dot{V}O_2$ values when compared to warm exposure (Craig & Dvorak, 1969, & Holmen & Bergh, 1974). However, when thermal protection is provided by a neoprene wet suit, the usual response to cold water is blunted by providing enough thermal protection for the diver against the 18 °C temperature.

There really was very little difference in $\dot{V}O_2$ found between the two warm water dives. The warm water dive with thermal protection produced slightly lower $\dot{V}O_2$ values than the warm water dive without suits. Evidently diving without wet suits, even if diving in the "tropical like" (29 °C) water temperatures, results in a greater cooling affect on the divers than if they had been wearing suits. This assumption is supported by the caloric expenditure, $\dot{V}_E$, and core temperature responses noted.

The results for $\dot{V}O_2$ and core temperature for this particular study differed from those of Costill, Cahill et al. (1967). Costill and co-workers compared swimmers who swam for 20 minutes at a sub-maximal self selected pace in 17.4 °C, 26.8 °C, and 33.1 °C. They found no significant differences in $\dot{V}O_2$ between the three water temperatures. They also observed an increase in rectal temperature during all three water temperatures. The results from the present scuba study indicated that there were significant differences in $\dot{V}O_2$ and core temperature between the two water temperatures (18 °C & 29 °C) for divers without wet suits. One might hypothesize that in addition to the workload of swimming (utilizing leg and arm movements) versus finning (just leg movements), the self selected swimming pace was greater than the 35% max finning intensity. Both of these differences in research design (compared to the scuba study) may have created a higher metabolic load on swimmers, therefore swimmers generated more body heat while exercising, compared to the divers. This hypothesis is supported by a comparison of VO_2, and heart rate values for each study. Again the explanation might be that the shorter time period (20 min.) for swimming did not allow for greater cardiovascular, respiratory, or metabolic changes to occur.

Oxygen Consumption Responses During Normal Diving Conditions. Diving in warm water (29 °C) without suits is generally a comfortable experience assuming the exercise intensity is moderate and the length of time spent submerged is not long. Under these conditions (slight cold stress) one would expect the fatter diver to encounter less heat loss than the lean diver. One would also expect to see little or no change in core temperature in the fatter diver. However, considering the small number of subjects tested, their varying percent body fat and the fact that there was only one lean (n=1), one normal (n=1), and 13 (n=13) fat divers, statistical comparisons could not be conducted.

The results indicate that the fatter a diver, the lower his VO_2 and V_E when compared to the lean diver diving in warm or cold water with or without suits. During cold water diving, the excess adipose tissue acts as an insulator and modulates the expected (normal) physiological and metabolic responses which would be observed in a lean diver diving in cool or cold water temperatures.

The cold water dive with suits produced VO_2 values which were 3.5% lower than those found in the warm dive without suits. Although not significant, examination indicated that all VO_2 values during the cold dive with suits were lower than all VO_2 values during the warm dive without suits. This information would lead one to believe that the cold water dive with suits was actually less of a cold stress than diving in 29 °C without suits. This reasoning is substantiated by the significant increases observed in core temperature noted during the cold dive. Apparently, the wet suit offered more than adequate thermal insulation to the diver against the cold water temperature. Since core temperature did rise, one might hypothesize that this dive actually posed a relative heat stress to the divers, while the warm water dive without suits posed a relative cold stress.

Percent Fat, Oxygen Consumption and Water Temperature Relationships. In a study conducted by McArdle, Magel et al. (1984), resting VO_2 increased linearly (0.8 to 1.01 ml x min^{-1}) during 50 minutes of immersion in water from 28 °C to 24 °C in men with low percent body fat. However, in the same test men with an average percent body fat showed an increase in VO_2 only in the colder temperature (24 °C) while men with high body fat showed no change at all.

The results of this scuba study indicated that as body percent fat increased, VO_2 at a given water temperature decreased in relative and absolute terms. Subcutaneous fat adds insulation to the body, protecting it from heat loss. With less heat loss occurring one would expect to see smaller decreases in core temperature in the divers with higher percentages of subcutaneous fat, while submerged in cold water as compared to leaner divers. The divers in this study averaged 22.4% body fat, indicating that the 15 subjects as a group, were fatter than normal (Shilling, Carlston et al., 1984, suggests that "being more than 20% over ideal weight should disqualify" some divers from diving). One might expect fatter diver's VO_2 responses to be lower than those VO_2 values expected for a group of lean subjects during dives which impose a cold stress. Had the 15 divers been leaner one might expect to observe higher VO_2 values during each of the 4 diving conditions. With less insulation, heat loss would occur to a greater extent in cold environments, and caloric expenditure and oxygen consumption would rise in response to any drops in core temperature. With more insulation, heat loss would occur to a lesser extent. When core temperature rises, increases in caloric expenditure, oxygen consumption, and V_E would be observed. However, the increases observed during an apparent heat stress dive would usually be smaller than those observed during a cold stress dive because the cold dive would elicit higher VO_2 responses due to the workload of exercise and the added energy cost of shivering.

During swimming (breast stroke) in three different water temperatures of 17.4, 26.8 and 33.1 °C, it was found that oxygen consumption increased essentially in a linear fashion as swimming speed increased. The highest values for oxygen consumption at submaximal swimming speeds occurred in the cold water temperature without thermal protection. This "extra" oxygen cost of exercising in cold water is due mostly to the energy expended in shivering as the body tries to regulate core temperature (Nadel, Holmer et al., 1974). Research has been shown that competitive swimmers with no thermal protection find temperatures between 28 °C and 30 °C to be optimal (McArdle, Katch et al., 1986). This range in water temperature helps to transfer the metabolic heat generated in exercise to the water, yet the gradient for this heat flow does not cause any significant increase in energy expenditure or change in core temperature due to the cold stress (McArdle, Katch et al., 1986). Competitive swimmers swim at higher intensities than divers generally fin, and swimmers use more muscle mass (arms and legs) than divers do (legs only) while propelling themselves through the water.

When a constant-load exercise is performed at light to moderate intensity, the oxygen consumption rises rapidly at the start and then levels off and remains at a relatively steady rate throughout the activity period (McArdle, Katch et al., 1986). During the scuba testing, steady oxygen consumption values were not observed, instead a rise in VO_2 over time was noted during each dive. Since the workload remained fixed, one can assume that the four specific diving environments created an additional metabolic demand.

In part the results from this diving study support the information presented by McArdle, Magel et al., (1984). Since the dive in warm water without wet suits was conducted at 29 °C it might be expected that subjects would remain fairly comfortable while finning at the fixed submaximal workload, and in fact the divers reported that they felt comfortable. However, it was found that caloric expenditure, $\dot{V}O_2$ and $\dot{V}_E$ all rose during the dive in 29 °C water. This suggested that finning at a low intensity (35% of max) in 29 °C did in fact cause enough of a cold stress to elicit increases in caloric expenditure, $\dot{V}O_2$ and $\dot{V}_E$ significantly.

Since the warm water dive without suits elicited higher caloric expenditures, $\dot{V}O_2$, and $\dot{V}_E$ values and lower core temperature than the cold water dive with suits it can be assumed that the warm water dive created a greater cold stress to the divers.

Respiratory Exchange Ratio

There were significant differences found between respiratory exchange ratios during cold versus warm water diving with and without wet suits.

The importance of the respiratory exchange ratio ($\dot{V}CO_2/\dot{V}O_2$) is two fold. It is a factor which might explain the variation in the caloric expenditure expressed in (K/cal x min^{-1}) or (K/cal x Kg^{-1} x min^{-1}) and may also be an indicator of substrate utilization. Generally, during a fixed workload or at rest the R.E.R. provides the researcher with an indication of the fuel being metabolized. An R.E.R. near 0.70 indicates that fat is the predominant fuel source, whereas an R.E.R. approaching 1.00 would indicate a complete shift to carbohydrate fuels as the source of energy. The caloric equivalent per liter of oxygen consumed is increased when carbohydrate is the predominate substrate. During activities ranging from complete bed rest to mild aerobic exercise such as walking or jogging slowly, a mixture of nutrients is generally used, and the R.E.R. is intermediate in value between 0.70 and 1.00.

R.E.R. Responses During Diving. McArdle, Katch et al., (1986) states that work is generally accomplished with a greater dependence on anaerobic metabolism during submaximal exercise in heat than in cooler conditions. This then results in the early accumulation of lactic acid and as the level of lactic acid in the blood and muscles increases, the regeneration of ATP cannot keep pace with its utilization, fatigue sets in, glycogenolysis can not take place as readily and exercise must stop. The increase in lactic acid is probably due to: 1) the decrease in lactate uptake by the liver, because significant reductions in hepatic blood flow occur during exercise in heat (McArdle, Katch et al., 1986); 2) reduced muscle circulation, because large quantities of blood are shunted to the periphery for heat dissipation. Both of these factors might be responsible for early fatigue during moderate exercise in heat. With this information, one might hypothesize that as a diver's core temperature rises he should depend more on carbohydrates than fats as a fuel source. However, the results of this study suggest the opposite, as a divers core temperature increased, it appeared that R.E.R. decreased, possibly indicating a higher reliance on fats than carbohydrates as a fuel source. Research conducted by Timmons, Araujo et al. (1985) indicates that fat utilization is enhanced by exercise in a cold environment. Results from their research on exercising during a cold stress (cycling endurance) reflected a significantly higher reliance on fat utilization. The results from this scuba study again indicated the opposite. The cold stress dive apparently elicited a rise in R.E.R. over time, enhancing carbohydrate, not fat, utilization during diving. One possible explanation for this discrepancy (stated earlier) might be the effects that posture has on blood distribution and aerobic versus anaerobic metabolism (especially during submersion). While finning, the divers are submerged and in a horizontal position during which time blood pooling occurs in the thoracic area thus decreasing peripheral blood flow. With less blood flow to the periphery we might expect to have a larger blood supply available to the exercising muscles. If this hypothesis were true, then there would be a large supply of oxygen available to the exercising muscle, which might account for a shift more towards fat utilization and less towards carbohydrate utilization especially during submersion. However, this hypothesis does not fully explain the differences found, therefore further research should be conducted.

In this particular study the divers respiratory exchange ratio ranged from 0.82 to 0.91. The highest R.E.R. values were observed during the last portion of the cold water dive without wet suits, while the lowest values were observed during the last portion of the warm water dive with wet suits.

The general trend was for the cold water dive with suits to elicit a lower R.E.R. response than the warm water dive without suits, although not significant. The results indicated that cold stress elicited higher R.E.R. values in contrast to the literature cited above (which were not tests in water environments).

Caloric Expenditure (derived from R.E.R. and VO_2 values). The calculations of caloric expenditure indicated that the highest level of energy expended was found during the cold water dive without wet suits. The warm water dive without wet suits required the next highest level of caloric expenditure per minute. The lowest caloric expenditure occurred while diving in 18 °C water with wet suits. These results suggested that diving without thermal protection even in warm water created a cold stress to the diver. Had the warm water temperature been slightly colder, as is the case in some tropical waters, one would expect an even greater caloric expenditure. Also, had the temperature been much lower during the cold water dives, it might be expected that caloric expenditure would increase despite the use of a full 1/4 " wet suit. Diving in the 18 °C temperature with thermal protection does not appear to require as much caloric expenditure as either of the two warm water dives. These results, along with the results for core temperature and VO_2 support the hypothesis that the thermal protection added to the diver does indeed protect the diver from the cold stress that would normally be imposed on a diver in 18 °C water, and in fact imposed a relative heat stress.

When comparing the two normal diving conditions, it can be deduced that the divers were subjected to more cold stress while not protected by suits in warm water than if they were to dive with suits in water which is 18 °C or warmer for up to 30 minutes.

Had the dive time been extended, a caloric expenditure which reflects both the relative cold or heat stress imposed on the diver and the intensity of exercise required for finning a longer period of time would be observed. One might expect to see caloric expenditure increase at a faster rate during the cold and warm water dive without suits as time progresses due to the expected increase in heat loss to the surrounding water, and subsequent core temperature decreases.

This information on total caloric expenditure should be useful to the average diver. Most people can understand the concept of caloric expenditure better than they might be able to understand oxygen consumption or respiratory exchange ratio values and their relationship to caloric expenditure. Knowing what the caloric requirements are of diving during specific dive conditions should yield useful knowledge to divers. There are many potential risk factors which can lead to possible diving accidents or fatalities. For instance cold and arduous dives, increased age, low fitness level, high percent body fat, fatigue, and poor diet can all predispose divers to such things as decompression sickness, nitrogen narcosis, heart attacks, respiratory distress, and panic (Shilling, Carlston et al., 1984). If divers were made more aware of the physiological demands of different diving environments, they could possibly prevent such accidents or fatalities from occurring by applying some common sense when planning to dive during strenuous or stressful conditions.

Heart Rate

There were significant differences found between heart rates during cold versus warm water diving with and without wet suits.

The lower heart rate responses observed in water environments are in part due to the "diving bradycardia reflex", where face immersion causes a decrease in heart rate, and in part to the changes observed in blood distribution while immersed, which also caused a decrease in heart rate (Heller, 1897, Sterba and Lundgren, 1985).

Heart Rate Responses During Diving. A significant increase in heart rate from the beginning of the tests throughout the 30 minute finning session during two of the four experimental dives was observed, (H.R.s during both the warm water dives significantly increased over time). The changes observed in heart rate over time are not changes one might expect from individuals involved in a submaximal fixed exercise bout, instead one would expect steady heart rate values throughout the test. Apparently the diver's body composition and the specific environmental conditions, had an additive effect with respect to heart rate response. Specifically, the four experimental dives elicited an increase in H.R. over time in response to the workload plus the relative cold or warm stresses which were reflected in the increases observed in caloric expenditure during each dive.

The highest heart rates were achieved during the warm water dives with thermal protection. As stated earlier, during this dive many of the divers indicated with hand signals that they were uncomfortably warm. It appears that this relative heat stress elicited an increase in heart rate as a response and means of dissipating excess heat from the body, to such an extent that it produced heart rates that were significantly higher than those found during all other diving times and conditions. The cold water dive with suits also created an environment that was too warm for the divers. Divers most likely responded physiologically to the heat stress by increasing peripheral vasodilation and heart rate to assist in moving the blood to the periphery where heat dissipation normally occurs. The assumption that diving with suits imposed a heat stress, which in turn raised H.R. was corroborated by the data noted for $\dot{V}O_2$, and core temperature. Heat stress appeared to increase core temperature, H.R., and $\dot{V}O_2$. However the absolute $\dot{V}O_2$ values were less during heat stress dives than in the cold stress dives.

The lowest heart rate values were produced during the cold and warm water dives without wet suits. A significant difference in heart rates was observed between the identical time periods (minutes 6-10 & 21-25) for each warm and cold dive without suits. The results indicated that the warm water dive (not the cold water dive) without suits produced significantly lower H.R.s. when compared to the other dives. The expected lowering of heart rate with decrease in water temperature was not evident when comparing these two dives. It appears that the higher energy requirement during cold water dives (including shivering) overrode the effect of cold temperature on heart rate. The warm dive without suits elicited lower heart rates than did the cold dive without wet suits. The lower H.R. elicited in the warm water dive without suits might be due to the lower metabolic load encountered during that dive versus the cold dive without thermal protection. The total metabolic load during the cold dive (finning plus shivering) was greater than the metabolic load during the warm dive without suits (slight cold stress plus finning).

Even though the comparison of H.R. responses during dives without suits proved to be different than what the literature reports, when "without suit" diving was compared to "with suit" diving, the results found were supported by the literature (the greater the cold stress, the lower the heart rate) (Craig and Dvorak, 1968 and Holmer, 1980).

<u>Heart Rate Responses During "Normal" Diving Conditions</u>. When comparing the normal diving conditions, it was evident that the cold water dive with wet suits produced significantly higher heart rates than the warm water dive without suits (except during the first five minutes).

This might be explained again by assuming that the suit offered more than adequate thermal protection for the divers, hence they may have been heat stressed to some extent in spite of the cold water. This explanation appears to be supported by the higher core temperatures, lower caloric expenditure, and lower oxygen consumption values observed during this dive as compared to the warm water dive without suits. Diving in warm water without suits for prolonged periods of time appeared to have produced a cold stress which may have caused portions of the circulatory system to vaso-venoconstrict, and the heart rate to slow down as expected in cold environments. This assumption was again supported by core temperatures, caloric expenditure, and oxygen consumption values observed during this dive as compared to the cold water dive with suits.

Generally cold stress appeared to lower heart rates, while heat stress appeared to increase heart rates. Assuming that the divers responded to the "cold" stress by vasoconstriction, slowing of the heart rate, and conservation of heat, or vasodilation, quickening of the heart rate, and dissipation of excess heat during "heat" stress.

Core Temperature

There were significant differences found between core temperatures during cold versus warm water diving with and without wet suits.

Swimming in cold water places the swimmer or diver under thermal stress which is reflected in metabolic and cardiovascular adjustments that are different from those seen in warmer water. These responses are geared mostly toward maintaining a stable core temperature because heat loss from the body is relatively high in water temperatures below 25 °C. Heat loss is also greater in leaner subjects than in those who have greater percentages of body fat (Holmer, 1980).

As the body is cooled the blood vessels near the skin constrict with the first frigid shock, permitting the flesh and extremities to cool while an increased flow of warm blood is routed to the internal organs. A person's core temperature normally holds steady in very cold water for about ten minutes before it starts to fall, while the skin temperature at the extremities approaches the same temperature as that of the water (Nadel, Holmer et al., 1974).

Core Temperature Responses. The warm water dive with a suit produced significant increases in core temperature over time. The increase observed during this dive was not surprising, considering how much thermal protection divers wore in the 29 °C water temperature. These results again support the subjective reports made by the divers; that many were too warm during this particular test. Some of the divers reported that they were sweating during this dive and they said (after testing) that they felt sweat dripping down their faces on the inside of the mask. The diver with the highest percent body fat, actually terminated the warm water dive (with suits) early due to "perception of heat stress". His final core temperature was noted at 37.8 °C. Divers responded physiologically to the heat stress with an increase in core temperature because their body dissipated the excess heat at a slower rate than it was being produced. Heat dissipation was blunted by the wearing of the 1/4 " wet suit.

The only decrease in core temperature observed over time was during the cold water test without wet suits. The results of the cold water dive without thermal protection were not unexpected. During this dive there was a significant drop in core temperature from the start of the test to the 30 minute termination point. It appeared from the analysis of the data and from the subjective reports of the divers, that diving in 18 °C water without thermal protection, created an environment which increased heat loss. Two of the divers did not complete this test. The diver with 12.5% body fat aborted the dive after 25 minutes due to extreme cold stress, while another diver quit early due to leg cramps. The leaner divers responded by shivering uncontrollably after about 20 to 25 minutes into the test. The leaner divers also appeared to have the most trouble completing this dive. The diver with 9.8% fat completed the dive, but his core temperature continued to fall for 15 minutes following the test, indicating a large cold stress and eliciting the expected "after drop" of core temperature (Craig, & Dvorak, 1968). The three divers who felt comfortable during this dive all had a body percent fat of 29% or higher.

Testing has shown that highly trained (generally lean) athletes actually are at a disadvantage in the cold. Fat is of course an insulator, and a cold lake or river is one of the few venues where a fatter person has a survival edge. Trained, lean athletes lose body heat in the water at a dangerous rate, and it is thought that it is because they are so efficient at getting rid of heat (Pugh & Edholm, 1955).

Shivering and increased metabolism are the main responses to cold exposure that have traditionally interested thermophysiologists.

Hayward, Eckerson et al., (1975) described a relationship between metabolic rate and water temperature. At water temperatures between 5 and 18 °C, metabolism increased to almost four times resting level at the coldest temperature, but in no case was the increase large enough to prevent a fall in rectal temperature. The subjects in Hayward's study were immersed in cold sea water with light clothing and life jackets on, and they were resting (Hayward, Eckerson et al., 1975).

The results of Hayward, Eckerson et al., agree with the results of this particular study's cold water dive without suits. However, one must keep in mind that the divers were finning during testing, while the subjects in Hayward and co-workers' study were at rest. These results suggest that divers were not able to maintain thermal balance in the cold water even while finning at the 35% max workload.

Core Temperature Responses During "Normal" Diving Conditions. The warm water without suits dive produced a small but significant increase in core temperature (0.1 °C) during the 30 minute test. As suggested in Chapter IV, the divers were either slightly heat stressed during this dive, or more likely, they were actually cold stressed and the rise in core temperature occurred as a consequence of vasoconstriction at the body's extremities as a means of conserving heat in the face of a heat loss. The data on oxygen consumption, $\dot{V}_E$, and caloric expenditure support this assumption. Assuming that the divers are under a slight cold stress, one might expect to see core temperature eventually drop during extended dives in warm dive without suits.

Observations of core temperature during the cold water dives with suits indicated a significant increase from the start of the test until the 30 minute termination time. These results along with those for caloric expenditure, and oxygen consumption, support the hypothesis that diving with thermal protection in 18 °C water did not pose a cold stress to the diver. Most divers reported subjective feelings of being "very comfortable" during this dive. It appeared that the full 1/4" wet suit provided more than adequate thermal protection to the diver in 18 °C water.

Rate of Heat Loss In Water. Direct measurements of body heat loss have been combined with the usual measurements of body surface and core temperatures, using both direct calorimetry and the measurement of surface heat loss with heat flux transducers (Boutielier, Bouges et al., 1977). However, the relationship between heat loss and temperature change has proven to be very complicated. The rate of cooling, body size, and body fat are important variables to consider when predicting temperature change from heat loss. Slow cooling over a long period of time can result in rather large heat losses of about 300 kcal, with very little changes in either surface or internal temperature, and little metabolic response. The same amount of heat lost quickly by direct cold water immersion would cause large metabolic responses, and a large drop in skin temperature, along with a rapid fall in rectal temperature (Webb, 1976). The bigger a person is the greater his/her tolerance for a given heat loss and the smaller his/her body temperature change. The fifteen subjects in this study had an average body percent fat of 22.4%. Of these fifteen divers, one had an average percent fat (12.5%), one was considered to fall within the lean category at 9.8%, and the rest were 18.8% or above. The highest percentage of fat was observed in the youngest diver (34.5%, 33 years of age). Since the majority of the men in this study were large (surface area), one would have expected them to have a greater tolerance to heat loss and temperature change if they had been compared to smaller men.

Cooling rates observed during diving (exercising) are much slower than those observed by men immersed nude in cold water, however, long slow cooling may be a serious operational problem. It has been observed that during long, slow cooling although physiologically tolerable, men loose a large amount of heat despite the small change in core temperature usually observed (Webb, 1976).

Because core temperature changes occur slowly, and because long slow cooling occurs more often in diving, it might be hypothesized that (during the warm without suits dive) the small increase observed in core temperature would slow as time continues and may in fact show a decline if dive time were extended.

The lowest core temperatures, and highest VO_2 were observed during the cold water dive without thermal protection, while the highest core temperatures, and lowest VO_2 were observed during the cold water dive with thermal protection. The results for all four diving conditions produced the expected core temperature/oxygen consumption relationship as cited by previous studies (Wagner, 1963, McArdle, Katch et al., 1986, Webster, 1974). These results indicated that there was a strong relationship between core temperature and oxygen consumption responses during different diving environments.

Considerations

Relationship of Dive Time to Physiological/Metabolic Responses

The study was designed to last 30 minutes, which represented a typical dive time. In reality, dive time is determined by several factors: depth of the dive, number of dives done within a 12 hour period, diving environment, a diver's air consumption, and a particular diver's dive plan. Many dives in shallow water can last up to one hour. Deeper dives to 90 or 100 feet are generally much shorter, lasting only ten to fifteen minutes. Were the length of the four dives extended to 45 minutes or more, one might have observed more pronounced differences over time in the dependent variables that were monitored. If dive time were extended, one would expect to see much greater changes in core temperature during the cold water dive without wet suits, and may have seen eventual decreases in core temperatures during the warm water dive without suits. Studies and divers' subjective reports of cold stress indicate that diving for longer periods of time or doing several dives in one day do tend to chill the body slowly even in warm tropical waters (Webb, Troutman et al., 1979).

If core temperature responses were different during a longer dive, one would expect to observe differences also in $\dot{V}_E$, $\dot{V}O_2$, H.R., and R.E.R. Any particular responses observed would be related directly to metabolic demands of the diving environment and to whether the core temperature increased or decreased over time.

Wet Suits

Tests of wet suits have been conducted on swimmers (Beckman, 1963), and have demonstrated the effectiveness of the 1/4" suit to provide sufficient insulation for an underwater swimmer in 0 °C water generating 200 kcal/sq. m/hr. to maintain a normal core temperature for one hour. The problem with this is that much of the research neglects to specify not only what type of swimming (arms and legs, legs only, with fins, without fins) but at what intensity and depth. Also, the percent of body fat of individual swimmers tested is generally not known. Without such information the researcher is at a loss for making any sort of comparisons between studies, or drawing any accurate conclusions.

In this study, the divers wore a 1/4" wet suit and found diving in 18 °C water with suits to be fairly comfortable. However, diving in the warmer temperature tended to elicit subjective responses from the divers that they were uncomfortably warm. The diver with the highest percent body fat (34.5%) actually aborted the warm water dive with a wet suit, three minutes prior to the 30 minute mark because of subjective feelings of "extreme heat".

Even though a 1/4" wet suit might satisfactorily insulate the cold-water diver operating at a ten to fifteen foot depth, its' buoyancy would present a problem if the diver were to change depths. The greatest part of the insulation provided by foamed neoprene is based upon its trapped air. The volume of this trapped air, and therefore the buoyancy and the insulation of the suit, are inversely proportional to the water pressure. This decrease in insulation and buoyancy with depth is undesirable, and limits the usefulness of the wet suit for diving at depths. Although the neoprene wet suit concept of thermal protection for underwater diving has greatly increased the cold water tolerance time, it still has some deficiencies (Beckman, 1963).

Acclimated vs Unacclimated Divers

The subjects in this study varied considerably with respect to diving experience. Although subjects were screened to eliminate those who dove regularly on a professional basis, there still was a wide variety of divers who volunteered.

When acclimated and unacclimated divers were compared (Bennett and Elliot, 1975) at different depths in cold water, it was found that unacclimated divers had higher oxygen consumption, greater increases in heat production and thus greater heat loss. The unacclimated divers increased their heat production, for the most part, by moderate to violent shivering in submersion and under pressure.

Since the subjects were Navy divers and the subjects in this study were recreational divers, it might be hypothesized that the majority of the divers involved in this study would fit more into the category of unacclimated divers (with the exception of 2 subjects, one who dove often, and the other who taught sailboarding). If this assumption is correct we would then expect to see similar metabolic, thermal and cardiovascular responses to diving under pressure and cold stress as was found with the unacclimated divers in the study conducted on Navy divers (Bennett and Elliot, 1975).

Although the physiological characteristics of the Navy divers was not presented in the research, empirically, one would expect an elite group of Navy divers to be fit, highly trained, leaner and younger in comparison to this author's 15 volunteers. Therefore, one must consider that the Navy divers results may not in fact reflect what would have been observed if a different population of divers were tested.

Pool

The cost of cooling and accurately maintaining a water temperature well below the 18 °C employed in this study was prohibitive. The cost of draining then filling the pool with cold water, and the time constraints on pool use also prohibited conducting thorough pilot testing with regard to cold water exposure. Without these constraints the researcher might have been able to test divers in colder water. Conducting testing in a pool enhances the researchers ability to maintain control and accuracy, however pool conditions do not replicate open water conditions well. Open water environments place the diver under many different psychological and physiological stresses. Specifically, divers face conditions of low visibility due to turbidity and less light, currents, tides, thermoclines, unfamiliar situations, different depths, and threats of marine life. Any one or combination of these open water situations can increase anxiety and physiological stress level to an extent which could effect their cardiorespiratory responses and energy expenditure. Therefore, testing under ideal pool conditions possessed a limitation to this particular study.

Time of Day of Testing

Five of the divers completed their four experimental dives in the morning and ten in the late afternoon and evening. The time constraints put on pool use and the fact that all divers were employed full time did not allow the research dives to all be conducted during the same time of day. However, each diver did complete his four dives during the same time of day as that of his first dive. These differences in testing time could have had some effect on the results of this study. Ideally, subjects should all be tested at the same time of day to alleviate any differences due to variable testing times.

Prior Diet

Although divers were told to arrive at least 3 hours post meal and given instructions on the types of foods or liquids to avoid during the entire testing phase, there were still a variety of eating habits noted among divers. These differences in diet with respect to physiological and metabolic responses could have affected the results of this study (ie. R.E.R. values). Ideally, divers should be provided with a specific diet regime in order to provide some consistency with respect to diet and eating frequency.

Motivation

Providing the divers with adequate and equal amounts of motivation during the initial maximal graded tethered finning test was difficult. It was difficult to provide verbal motivational cues to divers while they were submerged. If, in fact, some of the divers did not push themselves to a maximal effort then obviously the calculated relative workload of 35% would be inaccurate. Any differences in fixed relative workload intensity would have an effect on the physiological and metabolic responses of the divers during each of the four experimental conditions.

Conclusions

Within the limitations of this study the following conclusions are drawn:

1. Diving in different thermal conditions did elicit significantly different cardiovascular, respiratory and metabolic responses.
2. Breathing frequency responses were affected by suit use and dive time. Specifically the results indicate that diving without suits produced a significantly lower breathing frequency when compared to diving with suits regardless of water temperature. The addition of the 1/4 inch foamed neoprene wet suits appeared to have restricted the diver's ability to breath normally thus impeding chest wall expansion.
3. Minute ventilation responses (all dives) were significantly affected by water temperature, suit use and dive time. Specifically the results (for normal diving conditions) indicated that diving in cold water with suits required a lower V_E than diving in warm water without suits (although not significant).
4. Breathing frequency and minute ventilation responses were affected by water temperature, suit use and dive time. Specifically, the results indicated that an inverse relationship exists between breathing frequency and V_E when comparing dives with and without suits. Diving in cold water with suits elicited higher breathing frequencies and lower V_E than diving in warm water without suits. The suits provided thermal protection to the divers yet restricted

the divers' respiratory movement such that chest wall expansion was smaller, resulting in an increase in breathing frequency to achieve a given V_E. The V_E decreased not as a function of changes in breathing frequency, but because cold water diving with suits required a lower caloric expenditure and lower VO_2, than warm water diving without suits.

5. Oxygen consumption responses were significantly affected by water temperature, suit use and dive time. Specifically, the results indicated that as dive time was extended, VO_2 increased significantly during three of the four diving conditions. Diving without suits elicited higher VO_2 values than diving with suits in both water temperatures (although not significant in every case). The trend observed indicated that diving while exposed to a cold environment elicited higher VO_2 values than while diving in a warmer environment.

6. Oxygen consumption and V_E relationship responses were affected by different diving environments. As energy expenditure increased VO_2 and V_E increased. The particular diving environment (warm without suit protection) created a larger physiological cold stress on the respiratory/cardiovascular system, resulting in the higher VO_2 and V_E values. Since VO_2 was higher during the warm water dive without wet suit protection than during the cold water dive with suit

protection, one can assume that more O_2 was needed to meet the energy demands.

7. The respiratory exchange ratio responses observed during the different diving environments indicated that the cold water dive with suits elicited lower R.E.R. responses than the warm water dives without suits. The R.E.R. values indicated that cold stress elicited higher R.E.R. values, and that heat stress elicited lower R.E.R. values, although not statistically significant.

8. The calculations for caloric expenditure indicated that the warm water dive without wet suit protection required slightly more k/cal per minute than did the cold water dive with suits. This suggests that diving without thermal protection even in warm water created a relative cold stress to the diver.

9. Heart rate increased significantly during the 30 minute finning session during the four dive conditions. Cold water diving with suits produced significantly higher H.R. values when compared to warm water diving without suits. These results suggested that the wet suits worn during the cold dive provided adequate protection against heat loss to the surrounding water. The lower H.R. observed during warm water diving without suits suggested that the 29 °C water created a cold diving environment. The results indicated that cold stress did in fact elicit lower H.R. responses

than found in thermally neutral or warm water conditions. The results suggest that both cold and heat stress dives caused an increase in H.R., with the H.R. for cold stress dives being lower than those observed during heat stress dives.

10. Core Temperature significantly increased during three of the four dives. The only significant decrease was observed in the cold water dives without suits. Core temperatures rose to a higher degree during the cold water dives with suits than the warm without suits. These observations along with the $\dot{V}O_2$, $\dot{V}_E$, and caloric expenditure responses add credence to two hypotheses: 1) warm water (29 °C) diving without suits does expose the divers to an environment where heat loss occurs slowly, though not reflected in core temperature decreases during the thirty minute dive, 2) cold water diving (18 °C) with suits exposed the divers to an environment where heat gain occurred slowly, and was reflected in core temperature increases during the 30 minute dive.

11. Body percent fat does play a role in cardiovascular and respiratory responses during diving in different environments. Those divers with higher body percent fat elicited lower $\dot{V}_E$, and $\dot{V}O_2$ values than the leaner divers during all four dive experiments.

12. The characteristics of recreational divers are quite variable. The divers have a wide range of body percent fat, age, diving experience, fitness level, training background, and dive in a variety of diving environments. They posses different cognitive and psychomotor skill competence and dive for a variety of reasons. Therefore, further research should be conducted in order to gain more accurate knowledge of physiological changes that occur in recreational divers while diving.

Recommendations

The following are recommendations to be considered during future studies.

1. Extend the testing time beyond 30 minutes.
2. Perform the experiment at various depths.
3. Alter the water temperatures. Study responses at lower water temperatures; lower than the 18 °C (for the cold temperature), and lower than the 29 °C (for the warm temperature).
4. Study divers exercising at workloads higher and lower than the 35% employed in this study.
5. Allow each diver the same amount of rest between dives. Design the study such that there are at least two days rest between the maximal stress test and each of the four experimental dives.

6. Control the amount of exercise divers engage in and their diet during the testing phase.
7. Conduct the testing in an open water environment.
8. Test different groups of divers in order to compare the following (during warm and cold water diving with and without wet suits):
   a. Compare physiological responses of lean, normal, and obese divers.
   b. Compare physiological responses of highly experienced divers with less experienced divers (base experience on the number of dives performed within a specific time period).
   c. Compare physiological responses of older divers to younger divers.
   d. Compare physiological responses of divers tested during different times of the day.
   e. Compare physiological responses of highly trained (fit) divers with untrained (unfit) divers.

Summary

The responses observed during each of the four diving conditions were generally supported by the literature. However, the results of this study do shed light on the fact that dive time, subjects' percent of body fat, thermal protection, and water temperature all play very important roles with respect to energy expenditure during scuba diving.

With specific reference to the normal diving conditions, the researcher summarizes the following:

The energy requirements of finning at 35% of max. water VO_2 in 29 °C without wet suits and in 18 °C water with suits elicited different physiological responses.

Breathing frequency responses were observed to be significantly higher (in most cases) during wet suit use when compared to diving without wet suits. The results suggest that the wet suit created a restriction to respiratory movement causing a decrease in chest wall expansion and tidal volume and a compensatory increase in breathing frequency.

Minute ventilation, oxygen consumption, and caloric expenditure values were observed to be slightly higher during the warm water dive without wet suits than the cold water dive with wet suits. Although not significant in most cases, there were definite trends for each of the above dependent variables. These results suggested that warm water diving without suits required a higher level of caloric expenditure than cold water diving.

Core temperatures and heart rates were observed to be significantly lower (during most time periods) during the warm water dive without suits compared to the cold water dive with suits. The results observed for core temperature and heart rate support the hypothesis that warm water diving posed relative cold stresses to the divers while cold water diving with suits posed relative heat stresses to the divers.

The author concluded that the two water temperatures used in this study, and the use or no use of thermal protection, did (in many cases) significantly affect metabolic responses of divers finning at a submaximal (35%) intensity for 30 minutes.

Therefore, it might be necessary for divers to wear some type of thermal protection in warm water dives to avoid increases in minute ventilation, oxygen consumption, and caloric expenditure when compared to cold water (18 °C) diving with suits. Wearing thermal protection during warm water diving (29 °C) would insulate the diver against unnecessary long slow cooling during extended dives. On the other hand, it might be necessary for divers to wear less thermal protection in cold water temperatures (18 °C or warmer) than was worn in this study, because cold diving with suit protection created a relative heat stress. It would be advisable for divers to wear thinner wet suits and/or not wear full farmer john wet suits. Instead, divers might want to wear 1/8" or 3/16" wet suits which consist of the pants and jacket only. Diving without hoods would also help to keep the divers cooler (Dachau, 1946-1949, & Beckman, 1963).

Diving while heat or cold stressed, has been associated with increased risk for decompression sickness (Lehner, Adler et al., 1985, Strauss and Samson, 1976) and nitrogen narcosis. Therefore it would be wise for divers to dive with the appropriate thermal protection, neither allowing themselves to become too warm nor too cold while diving.

One can conclude that any dive that imposes a heat or cold stress on the diver will most likely increase the divers caloric expenditure over time. In either case the body will try maintain thermal balance in the face of increased heat gain or loss.

In part, the importance of this particular research project may lie in future studies which follow the recommendations outlined and expand on the design of this particular study. The information which could be generated from studying the average recreational diving population could prove to be very useful to physiologists and sport divers alike.

The information which has been obtained from this study will prove to be useful to both sport physiologists, diving instructors, certifying agencies, and divers. The results from this research will be disseminated throughout scientific journals and recreational diving magazines to provide and emphasize both the scientific and practical implications of the results of this study. These results should increase the knowledge about recreational scuba diving and most importantly help to improve diving education and diving safety.

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APPENDICIES

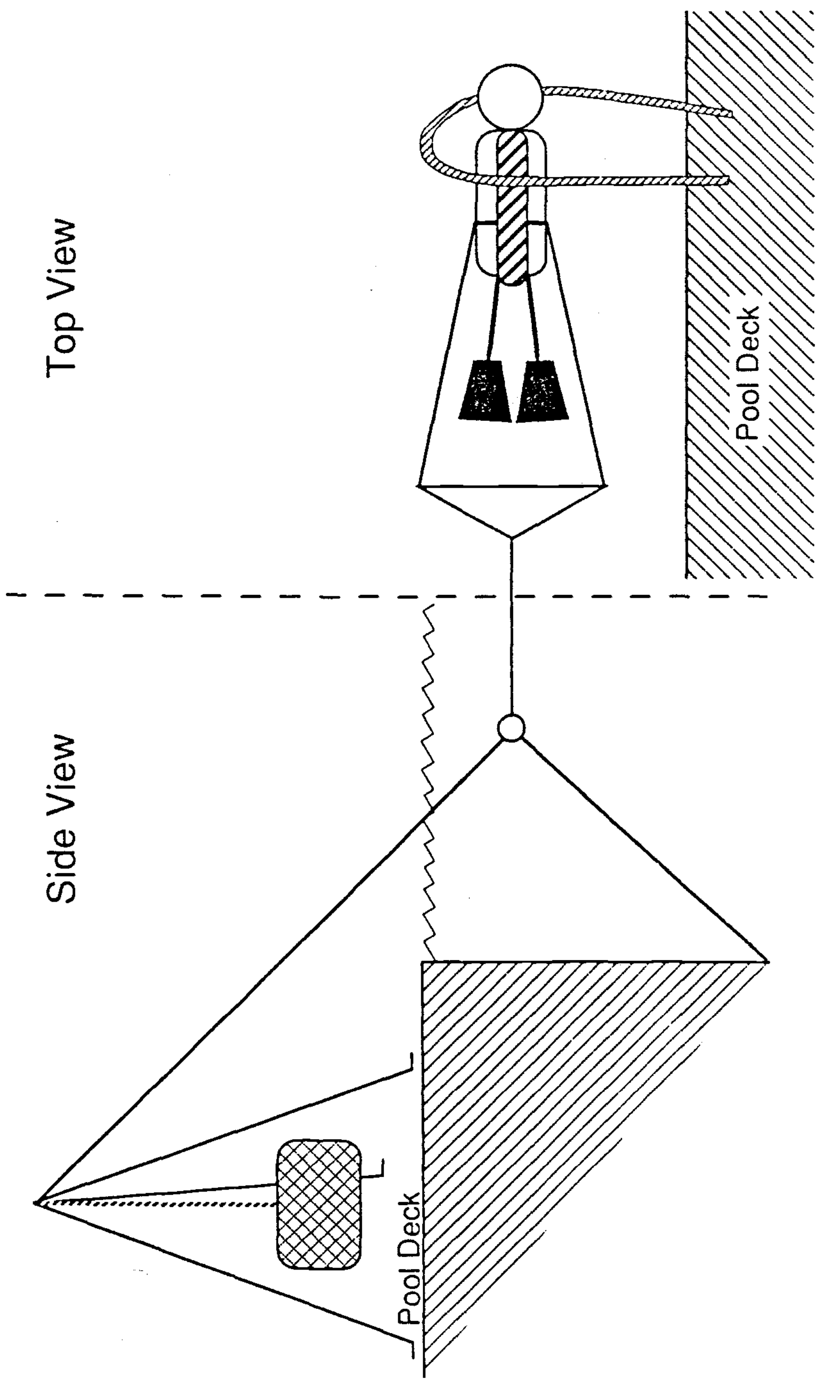
APPENDIX A

SCUBA EQUIPMENT

Mask
Fins (open heeled, adjustable strap)
Nose clip
Booties (1/4 inch neoprene)
Gloves (1/4 inch neoprene)
Wet suit (1/4 inch neoprene, farmer john & jacket)
Tank (71.2 cubic feet, steel, 2250 p.s.i.)
Weight belt with weights (adjusted to meet neutral buoyancy)
Buoyancy compensator (jacket style)

APPENDIX B

TETHERED FINNING/SWIMMING SYSTEM



APPENDIX C

DIET INFORMATION

Dear Diver,

First I would like to thank you for volunteering to participate in my research! Your time and effort on my behalf are greatly appreciated and I am really looking forward to working with you during the month of September.

Enclosed you will find the dietary instructions and diet logs which should be filled out according to the instructions for the three days prior to each of your tests. You may find that you dive on consecutive days, if so just log this and we can then take a look at the appropriate dietary logged days. Remember no Vitamins, Wheat Germ, or Yeast during September, and please restrain yourself from eating more than two bananas per day.

Assuming I have all your medical history, informed consent, and medical release forms (40 yrs +) then we will be set to start. If you should have any questions please call me as soon as possible. I look forward to seeing you soon.

Sincerely,

Caron Shake

APPENDIX D

CONSENT FORM

TITLE: THE EFFECTS OF WATER AND COLD WATER SCUBA FINNING ON CARDIORESPIRATORY RESPONSES AND ENERGY EXPENDITURE

INVESTIGATOR: Caron L. Shake

PURPOSE: Determine what physiological changes take place in certified recreational divers while finning at depth in cold and warm water with and without a wet suit. The following physiological measurements will be taken and recorded: breathing frequency, minute ventilation, oxygen consumption (relative & absolute), respiratory exchange ratio, heart rate, and core temperature.

PROCEDURES: All testing will be conducted in the Women's Building pool at Oregon State University. As a subject, I will report to the laboratory on five occasions for the following:

1. Introduction to researchers and explanation of testing procedures. At this time I will receive information on the purpose of the research, when to show up for each test, and what I will eat prior to each test (dietary log).

I will then participate in five scuba dives.

2. The first being an introductory dive (29 °C) which will allow me to become familiar with the diving equipment and testing apparatus. It is during this first dive where I will perform a maximal graded tethered swim test. This test will entail finning underwater tethered to a swimming pulley system. I will begin at a moderate speed and resistance progressing gradually, with changes in the tethered systems backward pulling resistance, to the highest intensity of finning I am willing to sustain. The test usually takes 8-12 minutes and will be over when I signal that I am fatigued, or when I am no longer able to fin against the weighted system.

3. The second dive will be in warm water (29 °C) where the I will fin at a depth of 1 foot for 30 minutes on the tethered swim system at 35% of my predetermined maximal aerobic capacity. My effort during this task will be at a level which is normally encountered during recreational diving. During this dive I will be with-out a wet suit.

4. The third dive will be exactly like the second but I will be wearing a wet suit.

5. The fourth dive will be in colder water (18 °C). I will be asked to perform the same test as done in test two. This dive will be done without a wet suit.

6. The fifth and last dive will also be in the colder water (18 °C) and I will perform the same test as done in test two but will be wearing a wet suit.

During each of the dives the researchers will be monitoring my breathing frequency, minute ventilation, oxygen consumption, respiratory exchange ratio, heart rate, and core temperature. They will withdraw 18 ml of venous blood (from a forearm vein, about 1 1/2 teaspoons) once just before each test and twice following each exercise test.

I am aware that each laboratory meeting will require about two hours of my time. I will perform each of the five dives on separate days so the total number of days I will spend in water testing will be five. Three days prior to each dive I will abstain from strenuous physical activity. I will also perform a maximal symptom limited treadmill test where my blood pressure, heart rate, and oxygen consumption will be monitored.

I understand that the test of maximal oxygen consumption (aerobic capacity) has a very remote chance of precipitating a cardiac event or even death. However, the possibility of such an occurrence is very slight, since I am a certified scuba diver with no known symptoms of heart disease, and since the test will be administered by trained personnel who will be monitoring electrocardiographic and other physiological responses to the test.

I am aware that the wearing of a rectal temperature probe and the placement of two electrodes on my chest may produce feelings of discomfort. I am also aware that finning while wearing a wet suit in warm water and finning without a wet suit in cold water may be thermally uncomfortable, but should not pose any problems with performing the dives.

I am aware that the blood sampling procedure follows standard, hygienic practices for blood withdrawal, and may leave a bruise at the site of needle insertion.

The benefits of my participation in the study include the contribution my involvement makes to the scientific process and the understanding of the physiology of recreational divers diving in cold and warm water. I will also gain knowledge of my cardiovascular fitness in swim finning, and treadmill walking. Involvement in this research will also provide me with knowledge of diving research which can then be credited towards receiving advanced scuba certification.

I understand that my results in the study will be kept confidential and that I will not be identified in any way in publications and presentations arising from this project. Specifically each diver will be given a number which will then represent them and their results.

I have been completely informed of and understand the nature and purpose of this research. The researchers have offered to answer any further questions that I may have. I understand that I may withdraw from the study at any time without prejudice or loss of the benefits to which my participation entitles me.

I understand that this research project entails the removal of approximately 18 ml of blood on 12 different occasions. The blood withdrawal will utilize hygienic conditions and I am at not risk of contracting Hepatitis B or HTLV III (AIDS) infections from these procedures. However, if I am a person who is at an increased risk of carrying Hepatitis B or HTLV III infection, I will not participate in the study.

If I experience any discomfort or injury during the course of my participation in this research project, I am to call Caron Shake at (503) 754-3221.

I have read the foregoing and agree to participate in this study.

Subject's Signature ________________ Date ________

Subject's Address ________________________________

Investigator's Signature ________________ Date ________

APPENDIX E

HUMAN SUBJECTS COMMITTEE

Investigator: Caron L. Shake

Purpose of Study:
Determine what physiological changes take place in certified recreational divers while finning at depth in cold and warm water with and without a wet suit. The following physiological measurements will be taken and recorded: breathing frequency, minute ventilation, oxygen consumption (relative & absolute), core temperature, and heart rate.

Methods:
The subjects in the proposed study will be certified male scuba divers who have dived no more than 45 times within the last year. Their participation in the study will entail the following assessments:

1. Test of maximal aerobic capacity in water.

Each subject will undergo an exercise test tethered to a weighted swim system. The test will begin at a light workload and the intensity of the exercise will be increased at two minute intervals by increasing the weight in the swim system. The divers will be asked to maintain body position against the increasing backwards pull of the weighted system. The test will proceed until the subject indicates is no longer able to support the weight in the tethered system, this usually occurs within 8-12 minutes. Heart rate will be continuously monitored electrocardiographically. The subject will breathe through a gas collection hose and exhaled air will be collected and analyzed for oxygen and carbon dioxide concentrations to permit the determination of oxygen consumption. Trained laboratory personnel, certified in cardiopulmonary resuscitation, will be administering the tests.

2. Diving tests.

Following the maximal test each diver will dive a total of four times. Twice in warm water (29 °C) and twice in cold water (18 °C) at a depth of one foot for 30 minutes. One dive in the warm and cold water will be performed without a neoprene wet suit and one dive in the warm and cold water will be performed with a wet suit. Each of the four dives will be set at a relative workload of 35% of the divers predetermined maximal oxygen consumption.

During each of the four dives, trained personnel will monitor breathing frequency, minute ventilation, oxygen consumption, respiratory exchange ratio, core temperature, and heart rate continuously.

a. Breathing frequency and minute ventilation will be measured using a Parkison Cowan CDX gas meter.

b. Oxygen consumption will be monitored by having the diver breathe through gas collection hoses connected with a (Daniels) one-way breathing valve. Expired air will be collected and analyzed using standard open spirometry procedures.
c. Respiratory exchange ratio is monitored with the oxygen/carbon dioxide analyzer system.
d. Heart rate will be monitored electrocardiographically.
e. Core Temperature will be monitored with a specially designed rectal temperature probe. This waterproof flexible probe is 30 feet in length and will be attached to a surface Tele-Thermometer which is a battery powered instrument used for measuring a wide range of temperatures.

3. Plasma Beta-Endorphin/ Vitamin B-6.
Prior to the dives and twice following the dives, approximately 18 ml. of blood will be withdrawn from an antecubital vein. The blood will be withdrawn by a trained phlebotomist utilizing standard venipuncture procedures. Plasma from the blood sample will be analyzed to determine the concentration of Beta-Endorphin. To asses plasma volume changes hemoglobin and hematocrit concentrations will also be obtained from each of the blood samples.

4. Meals.
Divers will be asked to eat no later than three hours prior to each dive, they will be asked to abstain from certain foods or supplements which are high in vitamin B-6. This should allow the researchers to maintain some control over diet.

5. Foreseeable risks or discomforts:
a) The blood withdrawal from venipuncture will be performed under hygienic conditions using sterile equipment. The procedure may leave a bruise at the site of needle insertion. Each blood withdrawal will be taken by a trained person.
b) The rectal temperature probe insertion should not be uncomfortable, once inserted and secured the diver should not be bothered. Trained personnel will be on hand to give instructions and help if needed.
c) Electrode preparation may require shaving of the two chest sites.
d) The risk in maximal exercise testing is one death per 10,000 tests in large, varied populations.* The risk in the present study would be considerably less, since the subject will be screened to exclude individuals with known symptoms of heart disease.

6. Benefits.
The subject will benefit from his participation in the research program by contributing to the scientific understanding of the physiological changes which take place during diving in different temperatures. The subject will gain information about his specific diving fitness status as a result of the maximal aerobic capacity test. Additionally each diver will have the option of receiving diving

credit towards an advanced certification with N.A.U.I. or P.A.D.I. diving associations.

*American College of Sports Medicine. Guidelines for Graded Exercise Testing and Prescription (3rd Ed.). Philadelphia: Lea and Febiger, 1986.

APPENDIX F

DIVER INFORMATION

Name__________________Age________Occupation________________

Phone(w)______________(h)___________

Best time to reach by phone (w)________(h)___________

Address___________________________

Certification Agency_________________Year of Certification_______

Total number of dives______ Number of dives within the last year_____

Height_____ Weight_____

Do you currently exercise on a regular basis? ______If so briefly explain.

INSTRUCTIONS FOR DIVE DAYS

1. Three days prior to each dive test please refrain from strenuous exercise.
2. For a total of three days prior to each test please write down on the dietary log what foods you have eaten, how it was prepared and the approximate amount.
3. Bring with you your own suit, mask, snorkel, fins (open heeled adjustabel strap), booties, gloves, hood, farmer John 1/4 inch wet suit, and Bouyancy compensator. We can provide most gear however your own gear will fit you best so if possible bring it. (We will have fresh water with which to wash gear).
4. Arrive at the Womens Building (O.S.U. Campus) promptly (map included) and go down the stairs to your left to the end of the hall last door on the right.
5. Make sure you have already filled out the Medical Histroy, Informed Consent, and Diver information forms. For those divers over 45 please obtain a medical release from your physician. Bring all of this paper work with you if you have not already turned it in.

APPENDIX G

BREATHING FREQUENCY MEANS AND STANDARD DEVIATIONS FOR EACH OF THE FOUR DIVING CONDITIONS.

Time	(minutes)	Cold With Suit	Warm With Suit	Cold Without Suit	Warm Without Suit
1	5	19	19	20	17
2	10	20	20	19	17
3	15	20	21	19	18
4	20	21	21	19	17
5	25	20	21	20	16
6	30	21	22	20	17
SD ±		3.1	4.0	3.4	3.1

BREATHING FREQUENCY MEANS AND STANDARD DEVIATIONS FOR DIVES WITH AND WITHOUT THERMAL PROTECTION.

Time	(minutes)	With Suit	Without Suit
1	5	19	19
2	10	20	18
3	15	20	18
4	20	21	18
5	25	21	18
6	30	22	19
SD ±		3.5	3.6

APPENDIX H

MINUTE VENTILATION (L x min^{-1}) MEANS AND STANDARD DEVIATIONS FOR EACH OF THE FOUR DIVING CONDITIONS.

Time	(minutes)	Cold With Mean	Cold With SD(±)	Warm With Mean	Warm With SD(±)	Cold Without Mean	Cold Without SD(±)	Warm Without Mean	Warm Without SD(±)
1	5	22.3	4.9	21.7	3.7	29.7	9.4	22.8	5.7
2	10	22.3	4.2	22.0	3.8	25.3	4.9	23.0	5.5
3	15	22.5	3.7	21.8	3.9	27.2	6.7	23.0	5.3
4	20	22.3	3.1	22.4	3.4	28.3	7.6	23.0	4.9
5	25	22.4	3.2	22.4	4.1	29.0	7.5	22.4	4.4
6	30	22.1	3.4	23.0	3.6	28.9	6.7	21.7	3.3

APPENDIX I

OXYGEN CONSUMPTION (L x min^{-1}) MEANS AND STANDARD DEVIATIONS FOR EACH OF THE FOUR DIVING CONDITIONS.

		Cold With		Warm With		Cold Without		Warm Without	
Time	(minutes)	Mean	SD(±)	Mean	SD(±)	Mean	SD(±)	Mean	SD(±)
1	5	0.99	.19	0.97	.16	1.12	.20	0.99	.20
2	10	1.04	.19	1.02	.20	1.19	.20	1.08	.20
3	15	1.06	.20	1.03	.21	1.26	.26	1.09	.19
4	20	1.04	.18	1.03	.21	1.31	.28	1.09	.18
5	25	1.06	.19	1.08	.22	1.35	.27	1.09	.18
6	30	1.05	.19	1.13	.25	1.36	.23	1.09	.17

APPENDIX J

OXYGEN CONSUMPTION (ml x min^{-1} x kg^{-1}) MEANS AND STANDARD DEVIATIONS FOR EACH OF THE FOUR DIVING CONDITIONS.

		Cold With		Warm With		Cold Without		Warm Without	
Time	(minutes)	Mean	SD(±)	Mean	SD(±)	Mean	SD(±)	Mean	SD(±)
1	5	11.9	2.4	11.8	2.2	13.7	2.6	12.1	2.8
2	10	12.4	2.3	12.2	2.7	14.3	2.9	13.1	2.8
3	15	12.7	2.4	12.4	2.7	15.2	3.6	13.2	2.6
4	20	12.5	2.1	12.9	2.7	15.8	3.9	13.1	2.7
5	25	12.7	2.2	13.0	2.9	16.4	3.9	13.2	2.5
6	30	12.6	2.3	13.4	3.0	16.4	3.2	13.2	2.5

APPENDIX K

RESPIRATORY EXCHANGE RATIO MEANS AND STANDARD DEVIATIONS FOR EACH OF THE FOUR DIVING CONDITIONS.

Time	(minutes)	Cold With Mean	Cold With SD(±)	Warm With Mean	Warm With SD(±)	Cold Without Mean	Cold Without SD(±)	Warm Without Mean	Warm Without SD(±)
1	5	0.87	.07	0.86	.05	0.91	.08	0.88	.12
2	10	0.88	.06	0.86	.03	0.86	.06	0.90	.07
3	15	0.88	.05	0.84	.03	0.87	.05	0.91	.07
4	20	0.88	.05	0.84	.04	0.87	.05	0.89	.06
5	25	0.86	.06	0.83	.04	0.87	.03	0.86	.05
6	30	0.85	.06	0.82	.04	0.88	.07	0.85	.06

APPENDIX L

HEART RATE MEANS AND STANDARD DEVIATIONS FOR EACH OF THE FOUR DIVING CONDITIONS.

Time	(minutes)	Cold With Mean	Cold With SD(±)	Warm With Mean	Warm With SD(±)	Cold Without Mean	Cold Without SD(±)	Warm Without Mean	Warm Without SD(±)
1	5	98	11	103	14	96	17	94	13
2	10	101	13	106	15	98	16	97	14
3	15	101	13	106	13	98	14	98	14
4	20	102	16	111	13	98	15	98	13
5	25	103	14	114	15	98	15	97	13
6	30	103	14	118	16	98	15	98	12

APPENDIX M

CORE TEMPERATURE MEANS AND STANDARD DEVIATIONS FOR EACH OF THE FOUR DIVING CONDITIONS.

Time	(minutes)	Cold With Mean	Cold With SD(±)	Warm With Mean	Warm With SD(±)	Cold Without Mean	Cold Without SD(±)	Warm Without Mean	Warm Without SD(±)
1	5	37.6	.37	37.4	.41	37.4	.42	37.5	.42
2	10	37.7	.38	37.5	.42	37.4	.45	37.5	.45
3	15	37.7	.38	37.5	.39	37.4	.52	37.5	.48
4	20	37.8	.35	37.5	.38	37.3	.61	37.5	.50
5	25	37.8	.36	37.6	.53	37.3	.71	37.6	.51
6	30	37.9	.36	37.7	.38	37.2	.77	37.6	.52

APPENDIX N

OXYGEN CONSUMPTION (L x min^{-1}), AND ENERGY EXPENDITURE

There was a significant interaction ($p < 0.0000$) found for time x temperature x suit.

Temp.	Suit	Min.	O_2 consumed Kcal/L	Kcal used per min.
W	W	1	4.825	4.66
C	W	1	4.838	4.78
W	O	1	4.500	4.83
W	W	2	4.850	5.02
W	W	3	4.862	5.03
C	W	4	4.862	5.05
C	W	2	4.875	5.07
C	W	6	4.875	5.11
C	W	3	4.875	5.15
C	W	5	4.875	5.16
W	W	4	4.875	5.22
W	W	5	4.877	5.27
W	O	2	4.877	5.28
W	O	4	4.877	5.30
W	O	6	4.877	5.32
W	O	5	4.899	5.35
W	O	3	4.899	5.36
C	O	1	4.899	5.48
W	W	6	4.899	5.53
C	O	2	4.889	5.81
C	O	3	4.910	6.18
C	O	4	4.924	6.46
C	O	5	4.924	6.67
C	O	6	4.936	6.71

KEYS:

Temperature:
- W = Warm
- C = Cold

Suit:
- W = With
- O = Without

Min.:
- 1 = 1 minute
- 2 = 2 minutes
- 3 = 3 minutes
- 4 = 4 minutes
- 5 = 5 minutes
- 6 = 6 minutes