

VOLUMETRIC GAS USAGE OF THE BASIC-SPORT SCUBA
DIVER IN WATER TEMPERATURES OF 18.3, 22.2,
25.6 and 29.4 DEGREES CELSIUS

by

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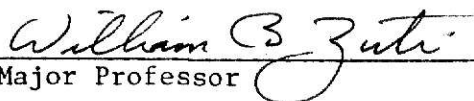
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Dedicated To My Parents

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CHAPTER 1

INTRODUCTION

As each year goes by, the number of people receiving diving certifications surpasses the previous year. In the five year period from 1970 through 1974, close to one million Basic Scuba Divers have been certified by the four national certifying organizations ¹(NASDS, NAUI, PADI, YMCA). With this increase, and the already huge diving population, over the two million mark since 1950, it is important to stress safety and dive planning.

New opportunities await the newly certified diver - Underwater Photography, Wrecking Diving, Ice Diving, Cave and Night Diving, just to name a few. Before a diver can enter any of these areas he must know his limitations and how to plan his dive. Dive Planning can be learned through any diving course; limitations are only learned through experience and diving. The most important limitation any diver faces is how long he can stay down. This question can only be answered if the diver knows his depth and, more important, his minute volume, more commonly referred to as breathing rate. If the diver does not accurately know his breathing rate, unexpected depletion of his air supply could occur, resulting in possible panic, free ascent or emergency swimming ascent. All three are capable of causing death by drowning, air embolism, or both.

The length of time an individual can stay down is commonly

¹See definitions for complete names

referred to as bottom time. It is directly related to air consumption; the slower the rate of consumption, the longer the bottom time. A number of variables affect the rate of air consumption. These include water temperature, diver fitness, diver experience, and amount of work performed (13, 38, 40, 41, 42, 43). Of the variables listed, only water temperature will be considered in this study. All the others remain the same during the dive and are individual characteristics that will not be considered for this study.

Water temperature can effect the diver in two ways. In water of 21.1°C and below, excess loss of body heat to the water can bring about undue fatigue and an increase in the air consumption, while water temperatures of 30°C and above might cause overheating, resulting in exhaustion (42, 43). The rate at which body heat is given up to the surrounding water depends upon the amount of protective clothing the diver is wearing. Water will conduct heat from the body approximately 20 times faster than air, for the same change in temperature (13). This loss of heat usually causes shivering, shallow breathing, and an increase in the rate of ventilation; consequently, an increase in air consumption. Since the efficiency of O_2 utilization is a function of fitness, and fitness is constant within an individual activity, any increase in O_2 usage will cause an increase in the ventilatory rate and result in an increased breathing rate.

As pointed out, a decrease in the temperature will result in an increase in the breathing rate, and an increase in the temperature beyond 29.4°C , will also result in an increased breathing rate. Therefore, a moderate increase in the temperature, higher than 21.1°C but lower than

30°C, will probably result in a decrease in the breathing rate. This concept is important in dive planning, especially in cold water of 26.6°C and below. High temperatures as defined by the U.S. Navy (42), 26.6°C and above, are the exception in diving and will not be included in this study. If a dive is planned for water temperature of 22.2°C, when in actuality the temperature is 14.4°C, an unexpected increase in the breathing rate will result, causing the dive plan to be altered.

For the newly certified Basic-Sport Scuba Diver, breathing rate plays an important part in dive planning and safety. Without an accurate breathing rate by which to calculate bottom time, safe dive planning is impossible. The only breathing rate the diver has available to himself is the one that his instructor has given him. Depending upon the text used by the instructor and his interpretation, breathing rate can vary from 18.3 l/min to 39.7 l/min (12, 13, 41, 42, 43), making dive planning impossible. Furthermore, there is no mention of how these rates were evolved in relationship to water temperature and the dress of the diver. Table 1 shows the difference in bottom times using the various breathing rates given in diving texts. Assuming all diving texts are correct in their given breathing rates, the diver is faced with choosing between at least four different bottom times, guessing at his dive plan and safety factors.

PURPOSE OF THE STUDY

The purpose of this study was to determine the mean volumetric gas usage of the Basic-Sport Scuba Diver at water temperatures of 18.3, 22.2, 25.6, and 29.4 degrees Celsius. More specifically, this study was to validate the present rates of air consumption given in various diving

Table 1
Bottom Times for Diving
Text Breathing Rates

<u>Reference</u>	<u>Work Load</u>	<u>Breathing Rate</u>	<u>Depth</u>	<u>Tank Size</u>	<u>Bottom Time</u>
12, 42, 43	0.93 Km/hr Swimming	18.13 Liters per minute	20.12 M	2.27 Cu.M	41 min.
41	Light Exercise	21.24 Liters per minute	20.12 M	2.27 Cu.M	35 min.
12, 13	1.58 Km/hr Swimming	28.33 Liters per minute	20.12 M	2.27 Cu.M	26 min.
12, 42, 43	1.85 Km/hr Swimming	39.66 Liters per minute	20.12 M	2.27Cu.M	19 min.

texts.

DELIMITATIONS OF THE STUDY

Nine male Kansas State University students, clothed in swim suit only, certified as a Basic Scuba Diver, having limited underwater diving experience, in good health and unaccustomed to breathing from a two hose regulator, were the volunteers for the study.

LIMITATIONS OF THE STUDY

The following items were impossible to control during the study and may have affected the results.

1. Individual adaptability to the water.
2. Rate of acclimation to the testing equipment and confined testing area.
3. Psychological effects of the water temperature.
4. Amount and type of food consumed before testing.
5. Time of day for testing an individual (the time of day for testing each subject was held constant).
6. Variability between subjects dealing with weight, height, and surface area.

DEFINITIONS OF TERMS

Air Embolism

When unvented pressure due to gas expansion forces air from the alveolae in the lungs into the blood vessels surrounding them, these bubbles act as dams when lodged in small vessels causing tissue to die (13).

Bottom Time

The interval from the moment a diver leaves the surface to the moment he starts his ascent, and not just actual time at the depth (41).

Air Consumption (Ventilatory Volume)

Amount of air used converted to Liters per minute (surface) for any underwater time.

Emergency Swimming Ascent

Dropping the weight belt, inflating the vest and kicking to the surface while exhaling continuously at a rate up to 91.44 Liters per minute, equipment on.

Free Ascent

Dropping all equipment and swimming to the surface while exhaling continuously at a rate of 18.29 Liters per minute.

Free Flow

Uncontrollable release of air from the regulator caused by reduction of pressure between the mouthpiece and the diaphragm on a two hose regulator.

N.A.S.D.S.

National Association of Skin Diving Schools.

N.A.U.I.

National Association of Underwater Instructors.

Novice Diver

Any diver not having logged 10 open water dives and having a minimum of 5 hours of underwater time.

Open Water

Any body of water that is not a swimming pool or has no specific boundaries that can be seen at all times.

P.A.D.I.

Professional Association of Diving Instructors.

Underwater Time

Interval from the time a diver starts his descent to the time he breaks the surface in his ascent.

Volumetric Gas Usage (Air Consumption)

Total amount of air used for a dive, surface corrected.

CHAPTER 2

REVIEW OF RELATED LITERATURE

The review of related literature will be presented in two sections: 1) Secondary Sources will be that information found in popular diving texts which are used by instructors and students, and 2) Primary Sources will be what research determines as the cause of increased and decreased air consumption rates. Throughout this chapter and the entire paper, all air consumption rates are corrected to surface conditions unless otherwise stated.

SECONDARY SOURCES

The first table presented in Chapter 1 (Table 1), lists four breathing rates in Liters per minute. Planning a dive to 20.12 meters using a 2.27 cu.m. tank and each of the listed breathing rates, bottom time is decreased as the breathing rates are increased. These differences in bottom time, caused by inconsistent breathing rates, make for unsafe diving procedures and planning.

Dueker (12), listed three breathing rates in his book on sport diving medicine, 18.3, 28.3, and 39.7 Liters/min. The air consumption rate of 18.13 Liters/min is based upon a swimming speed of 0.93 Km/hr. (0.508 m/sec.) which is usually considered to be a very slow swimming rate (12, 13, 40, 41, 42). Study of this text does not inform the reader as to the type of swimming performed, water temperature, subject dress, or the number of subjects tested to determine this average breathing rate. A swimming speed of 1.58 Km/hr. (0.8636 m/sec.), or

what is considered to be average swimming speed, will produce a consumption rate of 28.33 L/min. Swimming at 1.85 Km/hr. (1.016 m/sec.) will yield a consumption rate of 39.66 L/min. However, it is important to note that swimming speed is the only variable listed that affects the air consumption.

The Council for National Co-Operation in Aquatics presented an approximate breathing rate of 28.33 L/min. based upon average O_2 consumption and swimming speed. Swimming at a speed of 1.58 Km/hr. will yield an O_2 consumption of 1.4 liters/minute under normal conditions. Oxygen consumption is approximately one-twentieth of the total air consumption (surface corrected) making the breathing rate very close to 28.33 L/min. As seen with Dueker (12), and with the other text authors (21, 40, 41), there is no mention of how these rates were obtained.

A hypothetical breathing rate of 21.25 L/min. is given by Strykowski (40), in his book Diving For Fun. This consumption rate is based upon a diver doing light work at sea level, and states that only through increased exercise will the breathing rate increase. The individual reading such text is not informed as to the definition of light work; if the work is in or out of the water, or how the data were gathered to obtain this figure.

A slightly higher breathing rate, 19.26 L/min. is given by the U.S. Navy (41, 42), for swimming speed of 0.93 Km/hr. At this rate, and at a rate of 39.66 L/min. for a swimming speed of 1.85 Km/hr. there is no mention of how the data were gathered. The subject's diving level, sport diver, military diver, professional diver, was not mentioned within this text or any other text. Furthermore, the type of diving equipment

used for testing; such as hard hat, open circuit, closed circuit, semi-closed circuit scuba, was not listed.

PRIMARY SOURCE

Increased pressure is a condition encountered by divers which causes the body to modify its operations in order to function properly. While on the surface, the pressure exerted on the individual's lungs is $1.014 \times 10^5 \text{ n/m}^2$. While underwater, the pressure on the lungs is increased by $1.007 \times 10^4 \text{ n/m}^2$ for each meter in increased depth. This increase causes the respiratory muscles to work harder. Bartlett, Brubach, and Specht (3), found that in resting subjects submerged to their necks in seated and reclined positions, the amount of oxygen needed for breathing was approximately two times greater than in air. Hong and others (22), observed an increase of 60 percent, for subjects submerged to their neck in a seated position, in the amount of work required for breathing one liter of air in the water as compared to out of the water.

The tidal volume is that volume of gas that the individual ventilates through the lungs for each respiratory cycle, inspiration and expiration. Morrison and Butt (31), observed that when using a SABA open circuit supply system in depths of 1 through 8 atmospheres absolute pressure, the tidal volume is between 85-95 per cent of the individual's maximum volume for that particular depth.

The extra work the body must do in order to breath compressed gas in increased pressure is curvilinear according to Zechman, Hall, and Hull (46). This increased work is a result of increased air-way resistance due to breathing a gas of greater density (28, 36). This greater gas density is a function of Boyle's Law; when the temperature is kept

constant, the specific volume of a gas is indirectly proportional to the amount of pressure placed upon it. When using scuba, the volume of free air ventilated is the same regardless of the depth; only the density changes. This increase in density causes the body to modify its normal pattern of breathing in order to compensate for the extra work associated with breathing a more dense gas. Several investigators (15, 29, 35, 36), concluded that the body compensates for this increased gas density by decreasing the respiratory rate and increasing the tidal volume; all a function of air-way resistance. Air-way resistance causes the individual to inhale harder on the regulator in order to start the air flow, resulting in an increased volume of air per breath. Specht and others (38), observed pulmonary ventilation equal to about one-half of that achieved on land when testing underwater swimmers in a swimming basin.

The ability for work to be accomplished on land is 15 times greater than in water, regardless of depth, according to Specht and others (38). However, even though the work potential is lower in water than in air, the amount of oxygen needed by the body is equal to or surpasses that required on land. This can be attributed to many factors. The body position that the individual assumes while underwater will cause variations in the amount of drag placed upon the diver (19); thereby increasing O_2 consumption. Efficiency in the style of swimming performed and the type of equipment worn will affect work performance and air consumption (10, 18).

The amount of oxygen consumed by "fin" swimming divers has been measured by many authors. Lamphier (26), concluded that fin swimming

was approximately one-fifth as efficient as running or walking as a means of propulsion. They also observed that for a swimming speed of 1.5 Km/hr., the average trained swimmer uses 1.3 liters of O_2 per min. Swimming speeds above 1.5 Km/hr. causes inefficient utilization of O_2 , which will result in an increased oxygen consumption. Donald and Davidson (10), observed dissimilar results of oxygen consumption of 2.3 liters/min. or more for fin swimming at 0.67 - 0.95 Km/hr. Morrison (32), observed an average maximum oxygen consumption of 2.6 liters per minute for maximum fin swimming in depths from 1.83 to 84.12 meters.

Psychological factors can affect the amount of gas consumed as shown by Weltman, Christianson, and Egstrom (45), and Stang and Wiener (40). Novice divers tend to have a higher rate of air consumption than experienced divers given the same activity and water conditions. This may be accounted for by their inability to relax and/or to overact to unusual and new diving experiences. Most divers use their rate of air consumption as an index for steadiness and/or stability.

The immediate effects of cold water, 15.5°C and below, on scuba divers have been observed to include an increased oxygen consumption, increased lung ventilation, cause fatigue, hyperventilation, increased metabolic heat production, and increase total air consumption (20, 25, 41, 42, 43). Keatinge and Evans (24), concluded that upon sudden immersion in water of 5°C and 15°C , the increased ventilation was caused by a reflex response from the skin receptors instead of a decrease in the body core temperature. However, after a short time immersed, the increased ventilatory rate was attributed to the release of epinephrine.

Davis and others (8), indicate that with an increase in oxygen

consumption, skin temperature and heat exchange may increase. Hoff and others (17), concluded that there is a relationship between oxygen consumption and average skin temperature rather than immersion itself. Beckman (4), states two physiologic processes which limit heat loss from the body: 1) conductive loss from the skin, and 2) evaporative losses from the lungs. Heat loss by conduction requires movement of heated fluids, and heat loss by radiation requires transmission of electromagnetic waves of energy. In diving, the protective clothing worn by the diver blocks the transmission of heat. Therefore, their influence on heat loss is not significant and will not be discussed (42).

Water will absorb heat from the body approximately 20 times faster per unit of surface area than air for the same temperature change, according to Empleton (13), and Beckman (4). The National Research Council (33), concluded that the greater the difference between water temperature and skin temperature, the sooner air consumption will increase.

One mechanism for increasing metabolic heat production to counteract the effects of cold is shivering (14, 23, 30). Glickman and others (14), indicated that an increase in muscle tenseness and/or shivering will cause an increase in heat production, resulting in a greater oxygen production. The U.S. Navy (31), states that shivering will start when the mean skin temperature reaches 30°C and will intensify as the temperature decreases. Carlson and others (5), observed that the amount of shivering and the time it takes to occur in man depends upon his individual insulation and surface area per body volume. The greater the surface area per body volume, the faster shivering will

occur and O_2 consumption increase. The rate in which shivering occurs is a function of the amount of body insulation and the time it takes to cool the body surface to 30°C . Craig and Dvorak (7), and Hong and Rohn (21), concluded that an increase in the air consumption is directly related to the amount of heat loss, a function of time, water temperature, and the amount of shivering.

On the surface, loss of body heat through pulmonary ventilation can range up to fifteen per cent of the total body heat lost if the air is at 50 per cent relative humidity (work load unspecified) and the air temperature 37°C and below (9). In diving, air is inhaled at zero per cent humidity, and at a temperature far below that of the body's. Once it has entered the body, it is humidified, heated to body temperature and exhaled (2). The amount of heat lost to the air is proportional to the density of the gas, specific heat of that gas, and ventilatory volume (1, 2, 4, 9, 16, 20). Hoke (20), observed that metabolic heat production can be insufficient to offset the loss of body heat through the lungs if the dive is deep enough. This is easily observed when using gas mixtures of triox and heliox and diving below 90 meters. Helium is substituted for nitrogen, and the oxygen percentage is reduced to avoid the narcotic and toxic effects of those gases on the body when under pressure. Helium conducts heat better than nitrogen, and when mixed with oxygen, the specific heat of that mixture is much greater than that of air. The result is above normal heat loss through the lungs.

In water temperatures of 18.3°C to 29.4°C , Wells (44), observed a decrease in respiratory depth and minute volume as the water temper-

ature increased; above 26.6°C , respirations increased with shallow breathing due to the high water temperature. Russell, McNeil and Evonuk (35), observed that in cold water, air consumption was greater at rest and during exercise than in a dry normal environment. Moore and others (30), found a similar result using four water temperatures with light and moderate working levels. Using a rebreathing scuba outfit in 25°C water, Hoff, Frassetto, and Specht (18), observed oxygen consumption rates of 1.3 to 1.55 Liters/min., with a slightly higher rate of 1.69 to 1.92 Liters/min. in 22°C water. Observations were made by Lippett and Bond (27), on six Navy divers in full wet suits. Each subject performed work loads of rest, light and moderate work in water temperatures of 4.4° , 15.5° , and 26.6°C . The air consumption rates observed were then compared to existing rates found in the Navy gas manual. In the 4.4°C water all air consumption rates were greater than expected; 15.5°C water produced consumption rates similar to those listed; and 26.6°C water produced rates similar to those listed with the exception of moderate work, where the rates were lower than expected. It was concluded that air consumption rates were affected by water temperature and immersion time.

Based upon this research, what affect will water temperature have on the Basic-Sport Scuba Diver, and are the consumption rates listed in various diving texts usable?

SUMMARY

Four different breathing rates are given in popular diving texts used today by instructors and students in scuba diving courses. These rates are based only upon swimming speeds or work load. Research

establishes many variables that can effect air consumption. Increased pressure causes the body to work harder in order to breathe a gas of increased density and allows only an 85 to 95 per cent maximum ventilatory volume at the depth of the dive. Body position can increase or decrease the amount of drag produced depending upon the divers dress and efficiency of swimming. Swimming speeds above 1.48 Km/hr. are inefficient, causing an increase in air consumption. Experience, which affects psychological steadiness, can play an important part in air consumption. Heat is lost from both the lungs and skin. Increased air consumption associated with the heat loss is a function of skin temperature, time immersed, density of the breathing gas, specific heat of that gas, and the amount of shivering. Divers dress is associated with increasing and/or decreasing the air consumption depending upon the water temperature.

CHAPTER 3

PROCEDURES

The purpose of this study was to determine mean air consumption rates in four water temperatures and validate present values for the Basic-Sport Scuba Diver. This chapter includes the selection of subjects, apparatus used, testing location, safety, testing protocol, testing procedures and treatment of the data.

SELECTION OF SUBJECTS

Nine male scuba divers, certified Basic Scuba Diver by a nationally recognized organization, having limited open water experience, in good health and currently enrolled at Kansas State University volunteered as subjects. Prior to testing, each diver was required to complete an informed consent form (Appendix A), and obtain a medical examination; consisting of chest X-Ray, ear examination and general medical examination. Each subject was informed as to the potential hazards and problems that could occur during the study and were informed that they had the right to withdraw from the study at any time before they signed the consent form.

TESTING LOCATION AND APPARATUS USED

Testing took place in a 1.83m x 1.83m x 1.22m underwater weighing tank located in the Exercise Physiology Research Laboratory at Kansas State University. Equipment was placed and the subjects assumed a semi-seated position on support blocks located on the bottom of the tank. These blocks provided the subject the free movement he needed to perform

the kick during the test. Water temperature was monitored by a Van Walters and Rogers Total Immersion Thermometer and held within $\pm 0.6^{\circ}$ C of actual testing temperature by addition of hot and cold tap water.

Mask and fins were provided by the Kansas State University Physical Education Department for those subjects that did not have their own. Otherwise, the subjects provided their own equipment. This equipment was used throughout the study to assure consistency.

Fitsrite Adjustable Nose Clips were used on all subjects to assure that no air escaped through their nose during the testing period. They were placed on the nose and the mask placed over them. Stop Cock Grease was used to assure proper sealing of the mask for those people who had a moustache. The grease was applied in excess and worked into the hair so that the mask would seal with the grease, instead of the hair or skin.

Since the subjects were not wearing the breathing apparatus, a 6.80 kilogram vest was worn to provide negative buoyancy while testing. Negative buoyancy was necessary if the subject was to kick at the proper rate and not rise to the surface. To assist the diver in maintaining his testing position and neutralizing any movement caused by the kick, an expansion chinning bar was modified by sliding a 45.72 cm x 3.81 cm galvanized steel pipe over an end up to an expandable Ideal Clamp and placed in front of the subject (Figure 1).

Air for testing was provided from a standard 2.016 cubic meter steel Scuba cylinder and an 2.266 cubic meter aluminum Scuba cylinder filled with dehydrated, filtered, compressed air from the Kansas State University Physical Plant. The tanks were placed upon support blocks

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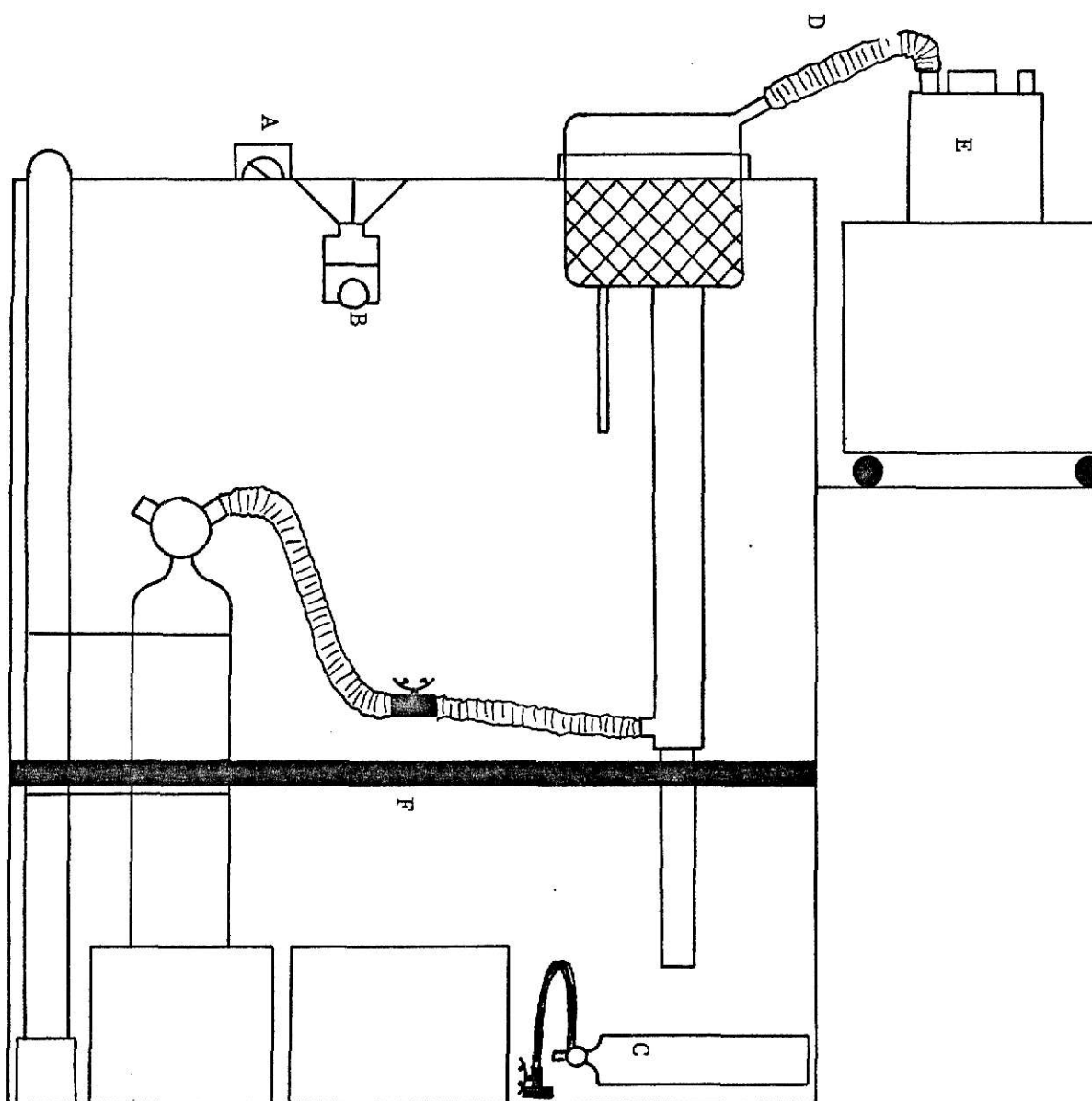


FIGURE 1: TESTING TANK

- A. Metronome
- B. Underwater Communication Unit
- C. Safety Pony Tank
- D. Flexible Connecting Hose
- E. Ventliometer
- F. Expansion Chinning Bar

on the bottom of the underwater tank and secured to the sump pump draining pipe for support (Figure 2).

The breathing apparatus consisted of a U.S. Divers single stage two hose regulator with modifications in the mouthpiece. A Costill-Willmore Valve was used as the mouthpiece valve to shorten the hose. One-way rubber flap valves used in all double hose regulators were used in the valve along with a Poseidon regulator mouthpiece. To avoid free-flow, the mouthpiece was positioned lower than the regulator housing and the regulator exhaust hose, disconnected from the housing, was positioned lower than the mouthpiece (Figure 2).

To determine tidal volume, all air expired was collected in a specially sectioned 6.35 cm diameter hose, now used as the regulator exhaust channel. The regulator exhaust hose was then joined to this section by a W.E. Collins Large Rubber mouthpiece inserted 6.35 cm from the bottom of the top section. Scotch Grip Rubber Adhesive 1300 Cement was used to secure the rubber mouthpiece into place, with the nibbs on the inside of the hose (Figure 3). This served as the joint in which the regulator exhaust hose could be placed into and sealed with Stop Cock Grease to assure an air tight seal. Attachment of the entire regulator exhaust channel to the nylon carboy was done by overlapping the channel hose to the pour spout of the carboy. To avoid excess water splashing in the carboy from the large bubbles rising up the channel, a metal screen was attached to the carboy pour spout before the exhaust channel was connected, to break up the air bubbles.

A 18.93 liter polyurethane carboy was used to collect the air exhaled by the subject and channel that air into a ventilometer and the

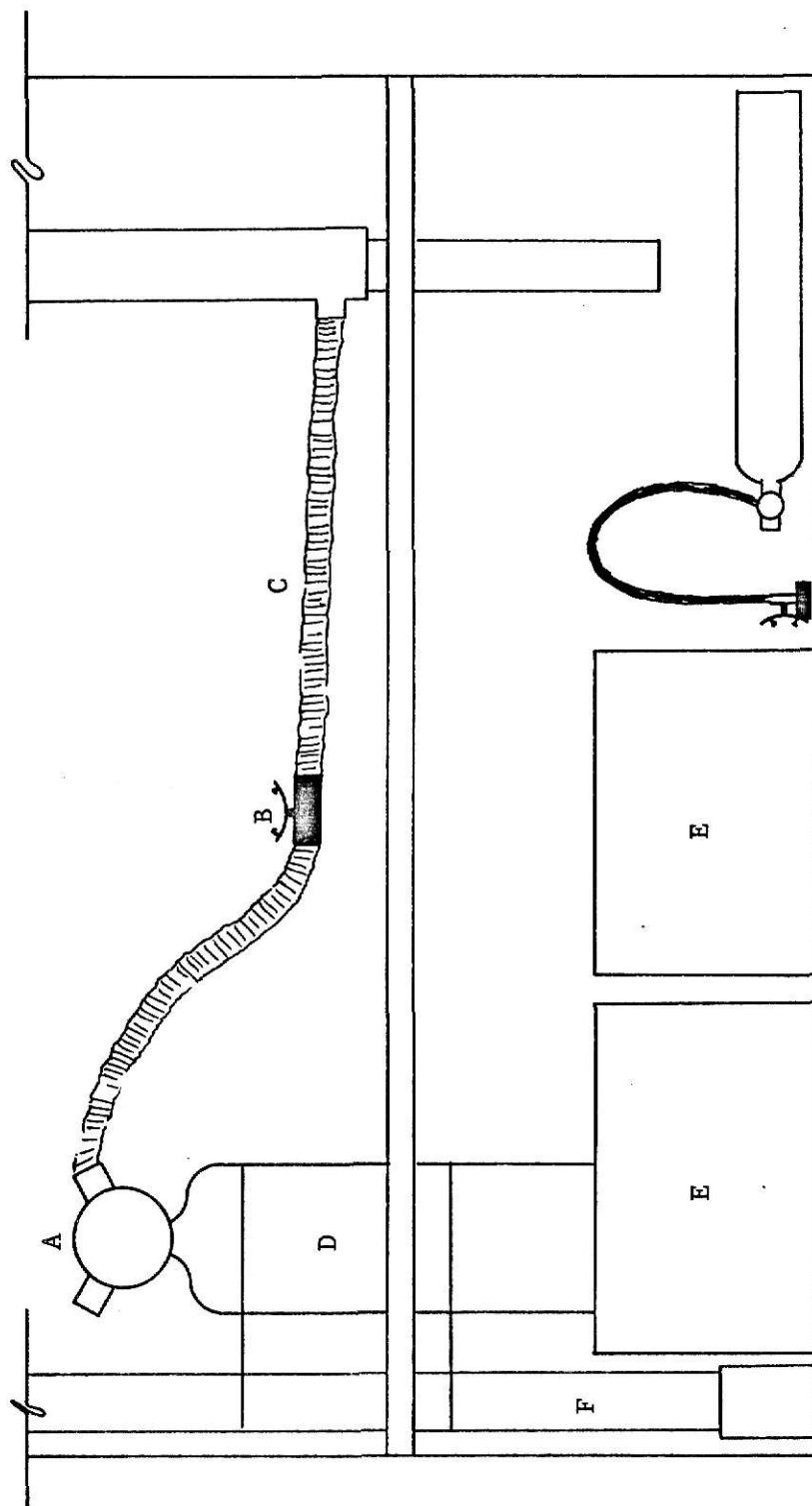
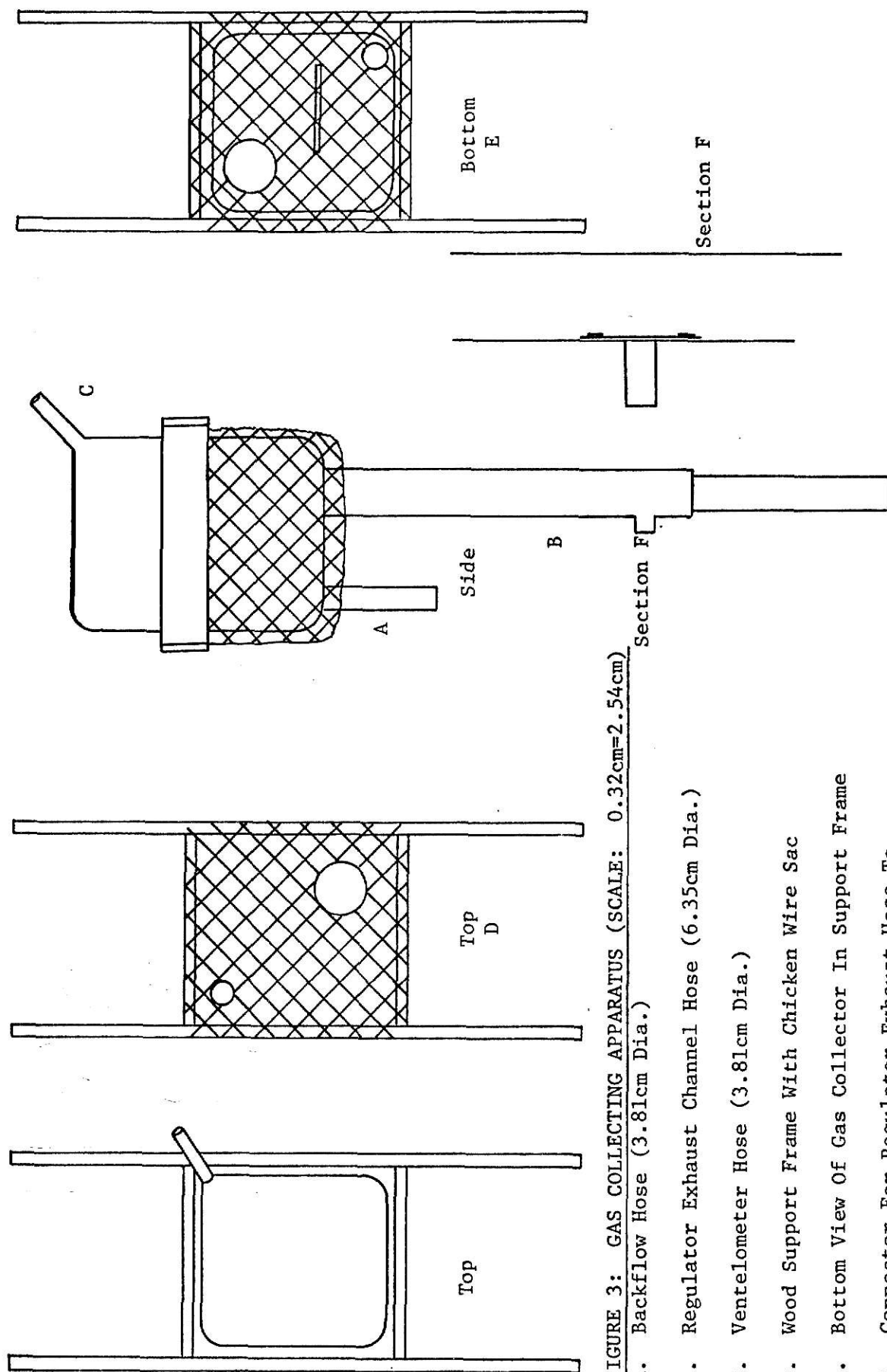


FIGURE 2: BREATHING APPARATUS

- | | |
|--|--------------------------------|
| A. U.S. Divers Single Stage Two Hose Regulator | D. Standard Scuba Air Cylinder |
| B. Modified Mouthpiece | E. Support Blocks |
| C. Exhaust Hose | F. Sump Pump Fixtures |



water back into the tank. Modifications on the carboy consisted of a 24.13cm x 3.81cm radiator hose glued and made air tight by Scotch Grip Rubber Adhesive 1300 Cement to a hole cut into the curved bottom side of the carboy, this was now the ventilometer hose (Figure 3). Another hose of the same dimensions and attached in the same manner as the ventilometer hose, was glued to the top of the carboy at a 45° angle to the pour spout, this acted as the backflow spout (Figure 3). The carboy was suspended above the water by a wooden frame, in the shape of a ladder with two rungs, and chicken wire was molded to fit the carboy modifications.

The air from the carboy was channeled through a Parkinson Cowen Ventilometer (PC Meter), by attaching airtight hosing to the ventilometer hose on the carboy onto the exhaust port of the PC Meter.

WORK LOAD

A pilot study was conducted to establish a fixed kicking rate that the diver encounters during the average swim. A rate of 46 kicks per minute was established for use by all subjects during the study. During testing, each subject was required to keep this kicking rate while in a semi-seated (slouched down) position on the support blocks and breathing off the apparatus, keeping their mouth below the housing of the regulator.

Work rate was broadcasted to the subjects using a U.S. Divers Yack Underwater Communications Unit, attached with tape by the vocal chord pick-up mike to a Franz Electric Metronome, Model LM-FB-4, set for audio.

SAFETY

All underwater apparatus used for the testing was "breakaway" equipment, allowing the subject a direct line to the surface if it was necessary. In the case of equipment malfunction, a 0.79 cubic meter pony tank with a Poseidon regulator attached and air turned on, was placed within easy reach to the left of the seated subject (Figure 2). On the surface, at least two researchers, trained in Scuba First Aid, CPR, and Artificial Respiration, were present during all test sessions.

TESTING PROTOCOL

Temperatures of 18.3, 22.2, 25.6, and 29.4 degrees Celsius were selected for testing. Extreme water temperatures, 18.3°C and 29.4°C, were selected on the basis of the comfort of an unprotected diver and the maximum water temperature encountered in Midwest diving. The middle two temperatures, 22.2°C and 25.6°C, were selected for their divisibility of the extreme water temperatures of ± 0.6 degree Celsius. Each subject was randomly assigned to a starting water temperature and randomly assigned to rotate until tested in each water temperature. Total underwater testing time was fifteen minutes. Before the starting test, each subject had his height and weight recorded.

TEST PROCEDURES

Before entering the water, each subject was informed about the water temperature and carefully instructed on how to find and operate the emergency equipment, how to use the test equipment, and how to sit once the equipment was in use.

All subjects were assisted into the water and assisted with the

positioning of their mask, fins, nose plug and weighted vest. The subject was then told to check his mask seal and listen for the beat from the metronome, because once the test started and the mask leaked, they were not allowed to clear it. Following this check, 1) they were told to take a breath and submerge when ready; 2) hold the regulator mouthpiece below the level of the regulator housing; 3) turn on the air and obtain the testing position described by sliding underneath the chinning bar; and 4) expect the regulator to be hard to clear. The kick was started when the subject was breathing off the apparatus. To avoid free flow, the mouthpiece position was stressed when turning the air on and while sitting in the testing position.

A warm-up period of three minutes followed once the air was turned on and the kick started. This would allow the subject to get accustomed to the water temperature, breathing apparatus, and body position. Any changes needed during this period were communicated in writing to the subject.

Immediately after the warm-up, a period of ten minutes occurred in which total air utilization was monitored on the ventilometer. In order to measure the volume of air ventilated accurately, the readings on the ventilometer were always taken after the backflow of air. Backflow occurs when the air displaced by the water in the exhaust channel is drawn back into the carboy.

A two minute warm-down followed the actual testing period so the subject would not know when the testing period ended. To avoid any change in the air utilization from anticipation, the subjects were never informed as to what test phase they were entering. To eliminate any self-

monitoring, time pieces were not allowed to be worn.

After the warm-down, the subjects were signaled to come up. They shut off the air and made a free ascent to the surface. All the subjects were assisted out of their gear and the tank, then told what their breathing rate was for that particular water temperature. After the 18.3°C Celsius water only, a cup of hot broth was provided to help warm up the subjects.

TREATMENT OF THE DATA

Data collected consisted of height, weight, water temperature and volumetric gas consumption. From this data, surface area was calculated and air consumption (L/min., L/min./S.A., L/min./kg) was determined. Analysis of Variance and a multiple regression analysis were used to determine any relationship between combinations of water temperature, surface area and air consumption. Further, a prediction equation was fitted to air consumption (L/min., L/min./S.A., L/min./kg) to establish theoretical breathing rates based upon the data, and confidence intervals of 90 and 95 per cent were calculated based upon liters per minute of air used and water temperature.

CHAPTER 4

RESULTS AND DISCUSSION

The purpose of this study was to determine the mean volumetric gas usage of the Basic-Sport Scuba Diver in four water temperatures and to validate the present rates given in popular diving texts. This chapter presents the results of this study and a discussion of those results. The results include: (1) all statistical treatment of the data; and (2) a prediction equation for estimating air consumption.

The physical data, means and standard deviations of all nine subjects are presented in Table 2. The subjects were adult males with a mean age of 20.55 years, mean height of 180.34 cm., mean weight of 74.32 kg, and a mean surface area of 1.92 M^2 .

Table 2

Descriptive Data of
the Subjects

<u>Subject</u>	<u>Height (cm)</u>	<u>Weight (kg)</u>	<u>Surface Area (M^2)</u>	<u>Age</u>
1	187.96	75.0	2.00	21
2	182.88	80.4	2.00	20
3	187.96	85.6	2.10	26
4	176.53	75.3	1.90	21
5	167.64	64.0	1.73	19
6	185.42	75.0	1.98	20
7	173.99	68.0	1.80	19
8	175.26	65.6	1.80	19
9	185.42	80.0	2.04	20
Mean	180.34	74.32	1.92	20.55
Standard Deviation	± 7.21	± 7.25	± 0.12	± 2.18

All air consumption data are illustrated in Table 3. Air consumptions were measured in liters per minute and converted to express air consumption as a relationship of surface area and kilogram of body weight. Means and standard deviations of air consumption in each water temperature, as they are related to time, surface area and body weight, are presented in Table 4.

Table 4
Mean and Standard Deviation of Air Consumption
in Four Water Temperatures

Water Temperature	L/min.		L/min./kg		L/min./S.A.	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
18.3°C	25.39	6.36	0.3469	0.1079	13.28	3.86
22.2°C	19.32	8.18	0.2646	0.1234	10.15	4.67
25.6°C	15.62	4.41	0.2133	0.0713	8.19	2.64
29.4°C	23.05	8.01	0.3071	0.0856	11.89	3.64

Graphic illustrations of individual air consumption and water temperature are presented in Figure 4. These data seem to indicate a relationship between air consumption and water temperature. They show the lowest rate of air consumption for most individuals occurring in the 25.6°C water temperature.

Analysis of variance was used to determine any significant relationship between air consumption and water temperature. There were three analyses; (1) air consumption vs. time in minutes; (2) air consumption per kilogram of body weight vs. water temperature; and (3) air

Table 3

Air Consumption Data

Air Consumption

<u>Temperature</u>	<u>L/min.</u>	<u>L/min.</u> <u>Surface Area</u>	<u>L/min.</u> <u>Kilogram</u>	<u>Subject</u>
18.3°C	26.04	13.02	0.3472	1
	19.32	9.66	0.2403	2
	29.68	14.13	0.3467	3
	27.44	14.44	0.3644	4
	38.08	22.01	0.5950	5
	17.92	9.05	0.2389	6
	16.52	9.17	0.2429	7
	28.58	15.88	0.4356	8
	24.92	12.22	0.3115	9
22.2°C	22.12	11.06	0.2949	1
	13.72	6.86	0.1706	2
	15.40	7.33	0.1799	3
	34.72	18.27	0.4611	4
	32.22	18.61	0.5031	5
	10.64	5.38	0.1419	6
	14.56	8.09	0.2141	7
	12.60	7.00	0.1920	8
	17.92	8.78	0.2240	9
25.6°C	13.16	6.58	0.1755	1
	12.04	6.02	0.1496	2
	13.44	6.40	0.1570	3
	22.68	11.94	0.3012	4
	23.80	13.76	0.3719	5
	17.08	8.63	0.2277	6
	12.88	7.16	0.1894	7
	10.64	5.91	0.1622	8
	14.84	7.27	0.1855	9
29.4°C	24.64	12.34	0.3285	1
	29.40	14.70	0.3657	2
	41.44	19.73	0.4841	3
	25.48	13.41	0.3384	4
	20.44	11.82	0.3194	5
	14.00	7.07	0.1867	6
	17.64	9.80	0.2594	7
	18.76	10.42	0.2860	8
	15.68	7.69	0.1960	9

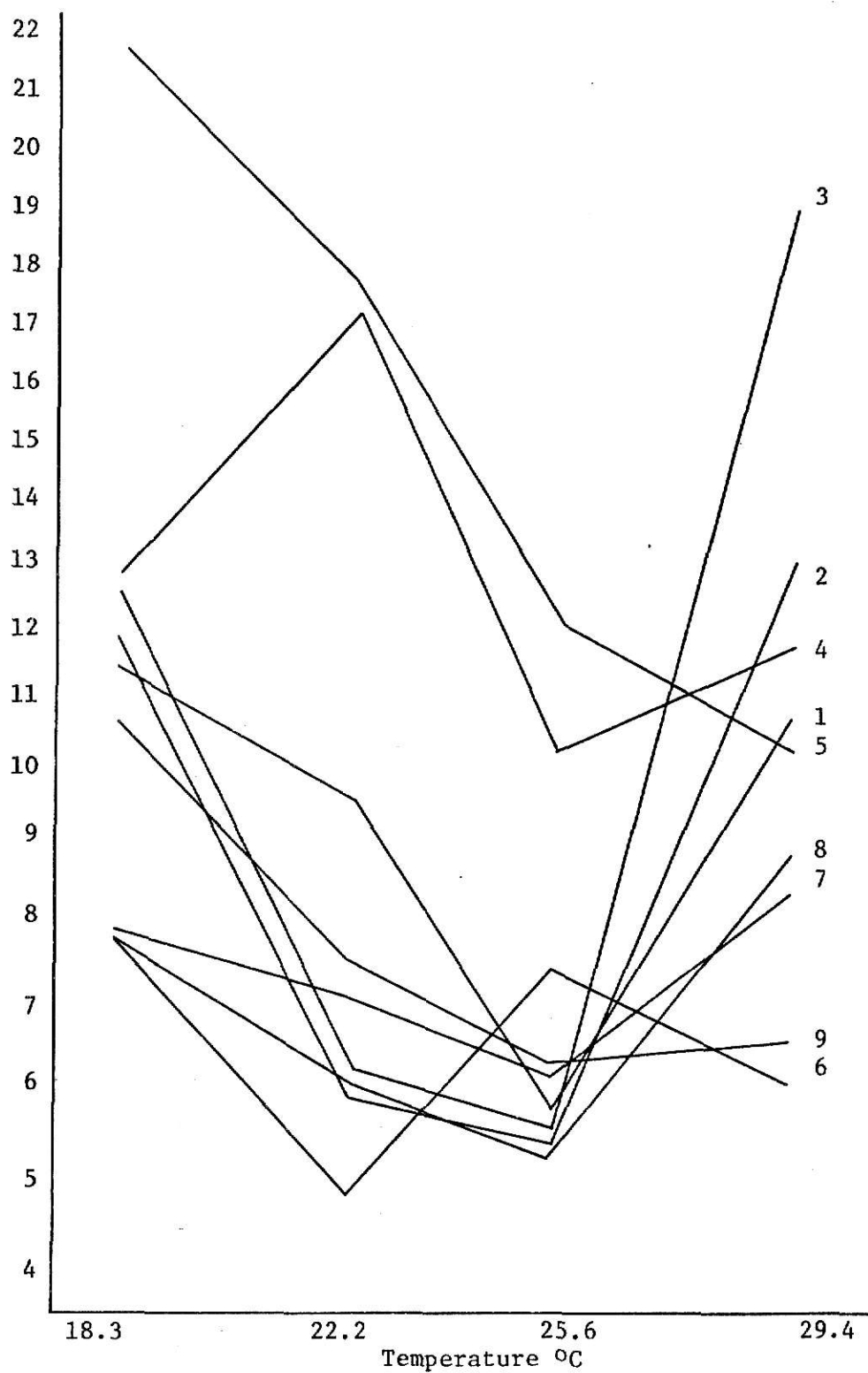


Figure 4

Individual Air Consumption
in L/min.

consumption per body surface area vs. water temperature. These results are illustrated in Table 5. For the range of water temperatures studied, the change in air consumptions with increasing water temperatures were quadratic.

Table 5

ANOVA for Liters/Minute, Liters/Minute/Surface Area and Liters/Minute/Kilogram

I.	ANOVA		Mean Square and Significance		
	Source of Variation	D.F.	L/min.	$\frac{\text{L/min.}}{\text{S.A.}}$	$\frac{\text{L/min.}}{\text{kg}}$
	Divers	8	104.95	35.11	0.0222
	H ₂ O Temps	3			
	Linear	1	49.03 ^{ns}	16.35 ^{ns}	0.0126 ^{ns}
	add. Quad.	1	410.33*	105.10*	0.0698*
	add. Cubic	1	37.19 ^{ns}	9.89 ^{ns}	0.0063 ^{ns}
	Error	24			
	Total	35			

ns = nonsignificant ($p > 0.10$)

* = significant at a 0.01 level

In view of the results in Table 5, a multiple regression analysis was performed to obtain a quadratic equation for predicting ventilation.

$$(1) \hat{Y} = a + b_1 (X_1 - \bar{x}_1) + b_2 (X_2 - \bar{x}_2),$$

where \hat{Y} = estimated average air consumption, a = constant, b_1 = partial regression of Y on X_1 , b_2 = partial regression of Y on X_2 , X_1 = water temperature in degrees C, $X_2 = X_1^2$, and the \bar{x} = the respective means.

Using the Method of Least Squares and substituting for the terms, the quadratic equation becomes:

$$(2) \text{ Estimated Air Consumption} = 160.56 - 11.285 (\text{water temp. } ^\circ\text{C}) + 0.2404 (\text{water temp. } ^\circ\text{C})^2$$

for L/min.;

$$(3) \text{ Estimated Air Consumption} = 82.10 - 5.976 (\text{water temp. } ^\circ\text{C}) + 0.1218 (\text{water temp. } ^\circ\text{C})^2$$

for $\frac{\text{L/min.}}{\text{S.A.}}$; and

$$(4) \text{ Estimated Air Consumption} = 2.13 - 0.1542 (\text{water Temp. } ^\circ\text{C}) + 0.003135 (\text{water temp. } ^\circ\text{C})^2$$

for $\frac{\text{L/min.}}{\text{kg}}$.

All the air consumption rates are corrected to surface pressure. The predicted air consumption rates for each water temperature using equations (2), (3), and (4) are given in Table 6.

Table 6
Observed and Calculated Air Consumption Using
A Quadratic Equation for Prediction

Water Temp.	L/min.		$\frac{\text{L/min.}}{\text{S.A.}}$		$\frac{\text{L/min.}}{\text{kg}}$	
	Obs.(Y ₁)	Calc(Y ₁)	Obs.(Y ₂)	Calc(Y ₂)	Obs.(Y ₃)	Calc(Y ₃)
18.3°C	25.39	25.88	13.29	13.53	0.3469	0.3581
22.2°C	19.32	17.98	10.15	9.46	0.2646	0.2517
25.6°C	15.62	17.09	8.19	8.94	0.2133	0.2372
29.4°C	23.05	22.65	11.89	11.69	0.3071	0.3064

Confidence intervals of 90 and 95 per cent, presented in Table 7, were calculated on the mean data for all water temperatures. These intervals estimate what the Basic-Sport Scuba Diving population would breath on the average, if they are well represented by the divers in this study.

Table 7
Confidence Intervals

<u>CI₉₀</u>	<u>CI₉₅</u>
$22 \leq \text{Ve}_{18.3} \leq 28$ L/min.	$21 \leq \text{Ve}_{18.3} \leq 29$ L/min.
$16 \leq \text{Ve}_{22.2} \leq 23$	$15 \leq \text{Ve}_{22.2} \leq 24$
$12 \leq \text{Ve}_{25.6} \leq 19$	$11 \leq \text{Ve}_{25.6} \leq 20$
$20 \leq \text{Ve}_{29.4} \leq 26$	$19 \leq \text{Ve}_{29.4} \leq 27$

DISCUSSION

The observed air consumption of the nine subjects, presented graphically on Figure 4, indicate an overbreathing or inefficient consumption rate for the 18.3 and 29.4 degree Celsius water temperature. This increase of air consumption in the 18.3°C water, can be caused by factors related to heat loss; 1) the body's reaction to sudden immersion in cold water, as described by several investigators (20, 25, 41, 42); 2) decreasing the mean skin temperature with water can cause an increase in the O₂ consumption (8, 16, 24); and 3) loss of body heat through lung ventilation can cause up to fifteen per cent of the body's total heat

loss (2, 9, 20). In an attempt to produce heat through metabolic actions, shivering, which is a factor for the increased air consumption, can occur.

An increase in the air consumption in the 29.4°C water temperature may be caused by the body retaining or producing too much heat. Body heat is retained by decreasing the effectiveness of water conductivity. This can occur when the body decreases its blood flow to the surface of the skin or when the water temperature is very close to the skin temperature (13, 33, 44). If the work load is too great for the conditions, an increase in body metabolism may produce overheating. Overheating can cause the breathing to be shallow and fast. This breathing rhythm will cause an increase in the respiratory rate and can eventually result in an increased use of air; that is, hyperventilation and/or hypercapnia (34, 42, 43).

The lower air consumption rates for water temperatures of 22.2 and 25.6 degrees Celsius, given in Table 3, indicate an increase in breathing efficiency and a reduction in the respiratory rate, as compared to the other temperatures. Figure 4 graphically illustrates that difference in air consumption. The decrease in air consumption rates could be attributed to the reduced heat loss caused by the increased water temperature. However, it cannot be generalized that these rates will hold true if the exposure time is increased.

Extreme differences in air consumptions are noted for one-third of the subjects. These differences can be explained by experience. Weltman, Christianson, and Egstrom (45), have indicated the part experience plays in diving activities. Since divers have various

aquatic backgrounds, air consumption will differ with the degree of apprehension of the water. The more apprehension the diver has, the higher his breathing rate. Likewise, the more experience the diver has, the less apprehension of the water he will possess.

Confidence intervals, illustrated in Table 7, were calculated in liters per minute at surface pressure to give the diver an estimate of his air consumption for planning a dive in water temperature of 18.3, 22.2, 25.6, and 29.4 degrees Celsius. Under NO circumstances should the individual base his dive plan entirely upon these figures. They represent a specific population and must be interpreted in relationship to that population, otherwise safe dive planning will not be possible.

The relationship between observed air consumption and calculated air consumption are graphically illustrated in Figures 5, 6, and 7. Use of the prediction equations and the resultant air consumptions calculated from it are restricted to the delimitations of this study.

This present study determined air consumption based upon water temperature, with a specific work load, underwater time, diver dress, and type of equipment. Consumption rates given in various diving texts were based solely upon work load. A comparison of these rates are illustrated in Table 8. The mean, standard deviation and range of the observed data was far below that of the dive text data, and more variables that can affect air consumption were accounted for with the observed data. The hypothesis that air consumption rates given in various diving texts are not related to those rates observed in this study is supported.

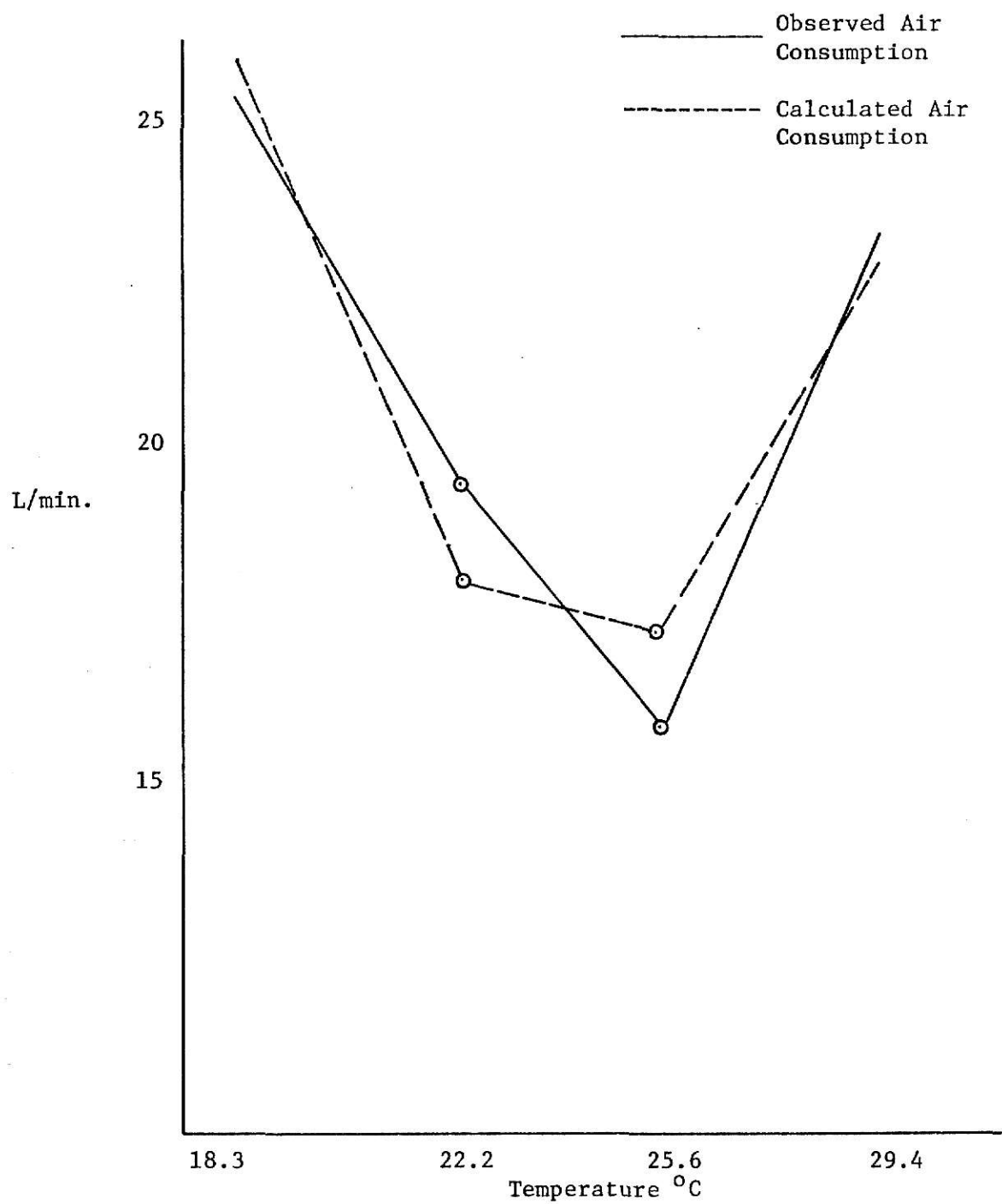


Figure 5

Air Consumption From Prediction
Equation in L/min.

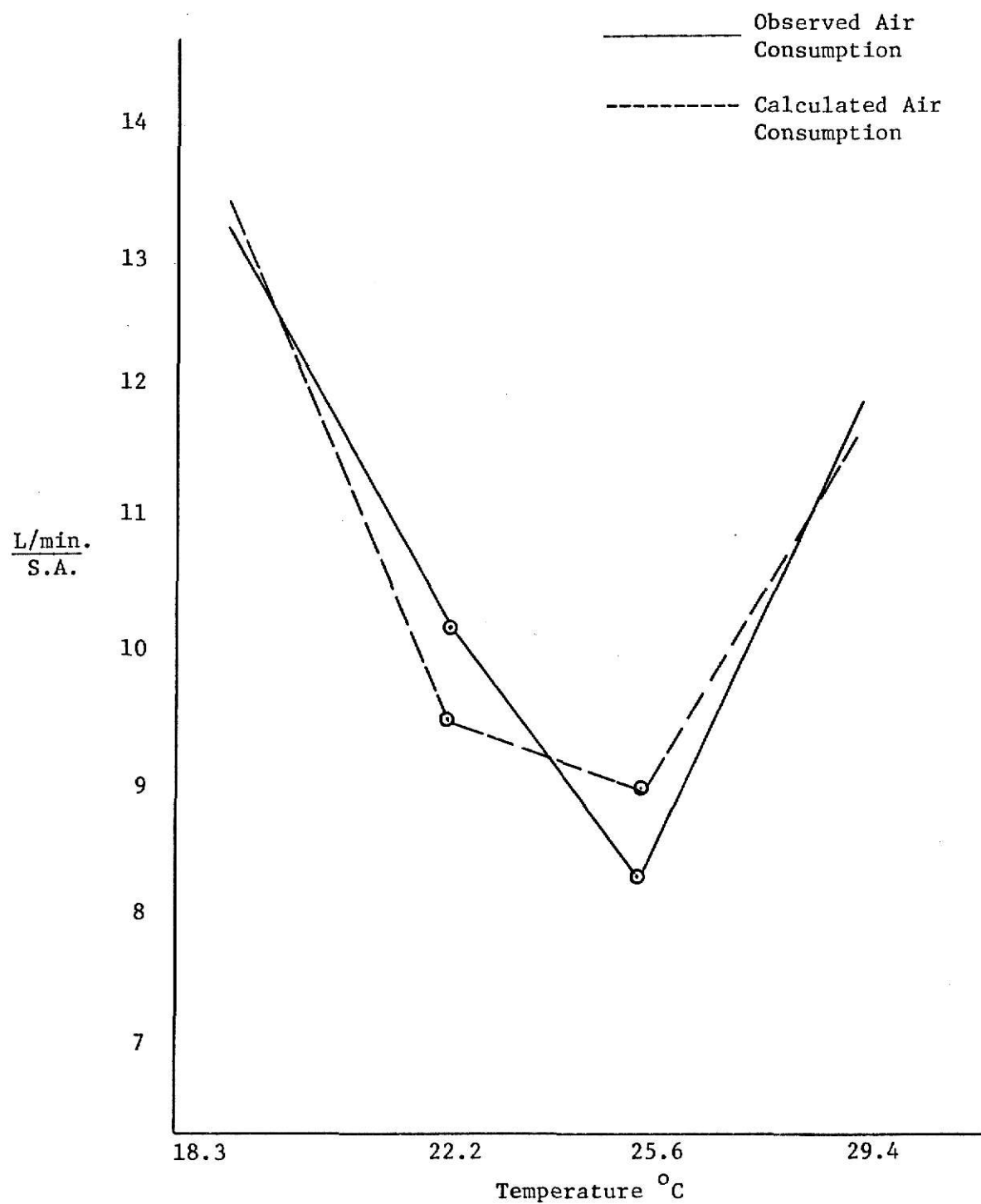


Figure 6

Air Consumption From Prediction
Equation in $\frac{\text{L/min.}}{\text{S.A.}}$

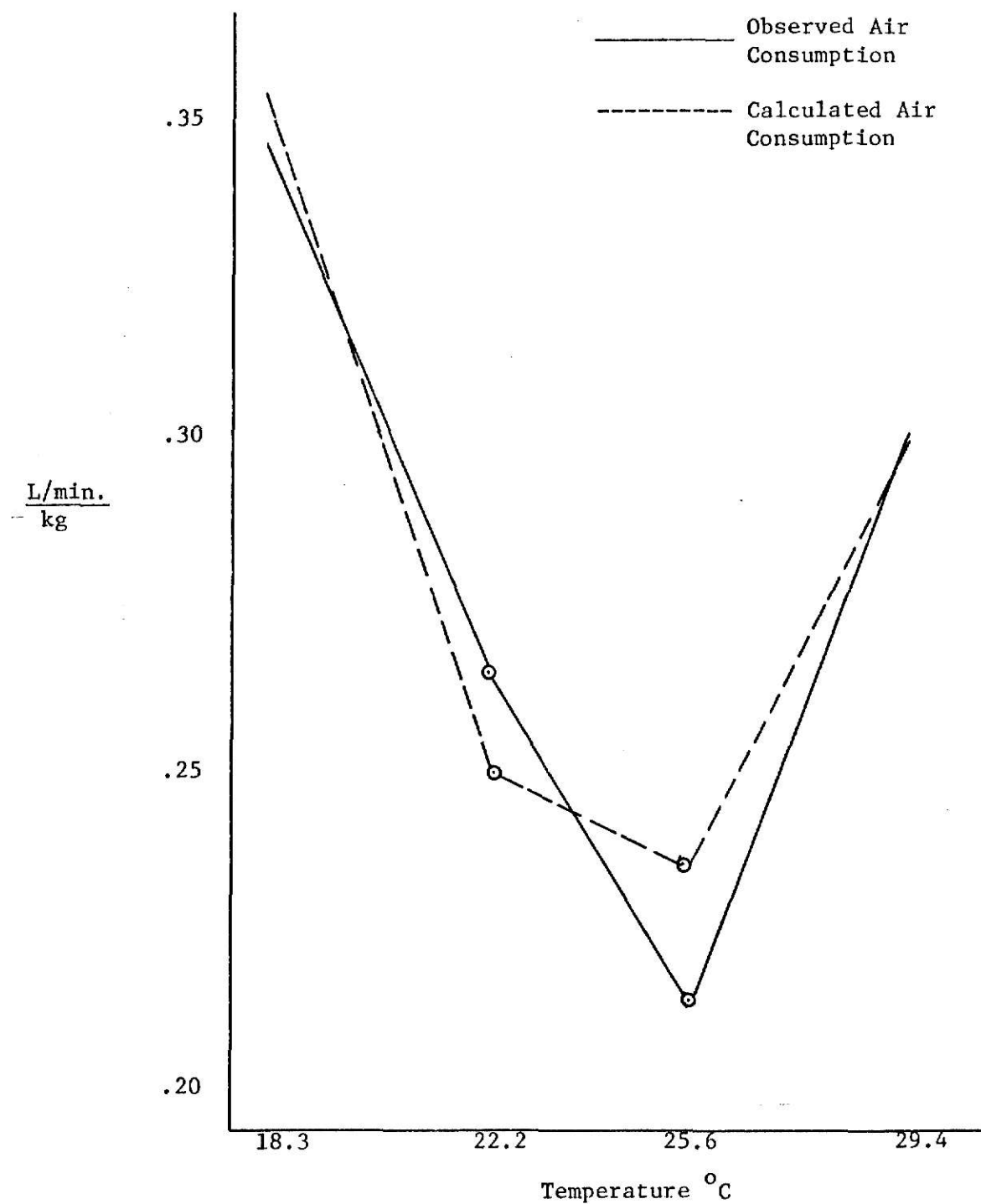


Figure 7

Air Consumption From Prediction
Equation in $\frac{\text{L/min.}}{\text{kg}}$

Table 8

Means, Standard Deviations and Ranges of
Various Diving Texts and Observed Air
Consumption Rates

<u>Source</u>	<u>Diving Texts</u>		<u>Observed</u>	
Dueker, U.S. Navy	18.13	L/min.	25.39	L/min.
Strykowski	21.24	L/min.	19.32	L/min.
Dueker, Empleton	28.33	L/min.	15.62	L/min.
Dueker, U.S. Navy	39.66	L/min.	23.05	L/min.
Mean	26.84	L/min.	20.84	L/min.
Standard Deviation	<u>+9.55</u>	L/min.	<u>+4.28</u>	L/min.
Range	21.53	L/min.	9.77	L/min.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Air consumptions of the subjects were measured for a ten minute period in four water temperatures. Based upon these data, the following conclusions were strongly supported.

1. Water temperature affects the rate of air consumption.
2. Air consumption rates observed during this study are lower than those listed in most popular diving texts.
3. A prediction equation was developed to determine air consumption based upon water temperature.

RECOMMENDATIONS TO THE DIVER

When applying these data to the diving situation, the following recommendations are made based upon the results of the study.

1. Water temperature should be considered a factor for the rate of air consumption when planning a dive.
2. Some precautions should be observed when applying these data (a) the dive should not be planned entirely upon the air consumption rates observed in this study since they represent a specific diver population not in an open water situation, and (b) consumption rates calculated and observed in this study may not be applicable if used for a longer underwater duration than that of the study.

RECOMMENDATIONS FOR FURTHER STUDY

Based upon this study, further research is suggested in the

following areas.

1. Further research should be performed on larger samples to include more of the novice diving population.

2. Further research should include a greater number of temperatures within the temperature range of this study and a longer bottom time interval.

3. Further investigations are recommended examining all physiological changes in the body caused by increased pressure on the body.

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APPENDIX A
SUBJECT CONSENT FORM

SUBJECT CONSENT FORM

The subject will be reclined in six feet of water performing a 12 inch flutter kick at 46 kicks per minute in the underwater weighing tank. Water Temperatures will be 18.3^o, 22.2^o, 25.6^o, and 29.4^o Celsius and immersion time will be 15 minutes at each temperature.

For and in consideration of permitting (1) _____ to participate in scuba diving research (see paragraph 1) done by Kansas State University, in the city of Manhattan, county of Riley, and the State of Kansas, Beginning on the ____ day of _____, 19__, the undersigned hereby voluntarily releases, discharges, wavers and relinquishes any and all actions or causes of action for personal injury, property damage or wrongful death occurring to him/herself arising as a result of engaging in said activity and for whatever period said activity may continue, and the Undersigned does for him/herself, his/her heirs, executors, administrators and assigns hereby release, waive, discharge and relinquish any act or cause of action, aforesaid, which may hereafter arise for him/herself and for his/her estate, and agree that under no circumstances will he/she or his/her heirs, executors, administrators and assigns prosecute, present any claim for personal injury, property damage or wrongful death against Kansas State University or any of its officers, agents, servants or employees for any of said causes of action, whether the same shall arise by the negligence of any of said persons, or otherwise. IT IS THE INTENTION OF (1) _____ BY THIS INSTRUMENT, TO EXEMPT AND RELIEVE KANSAS STATE UNIVERSITY FROM LIABILITY FOR PERSONAL INJURY, PROPERTY DAMAGE OR WRONGFUL DEATH CAUSED BY NEGLIGENCE.

The Undersigned for him/herself, his/her heirs, executors, administrators or assigns agrees that in the event any claim for personal injury, property damage or wrongful death shall be prosecuted against Kansas State University he/she shall indemnify and save harmless the same Kansas State University from any and all claims or causes of action by whomever or whatever made or presented for personal injuries, property damage or wrongful death.

The Undersigned acknowledges that he/she has read the following three paragraphs, has been fully and completely advised of the potential dangers incidental to engaging in the activity and is fully aware of legal consequences of signing the written instrument. It is also understood that the subject can withdraw at any time for any reason.

WITNESS: _____
Signature of Student

DATED: _____
Signature of Parent or
Guardian where
applicable

Information for numbered blanks:

(1) Subject's Name

VOLUMETRIC GAS USAGE OF THE BASIC - SPORT SCUBA
DIVER IN WATER TEMPERATURES OF 18.3, 22.2,
25.6, and 29.4 DEGREES CELSIUS

by

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AN ABSTRACT OF A MASTER'S THESIS

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The purpose of this study was to determine the mean volumetric gas usage of the Basic-Sport Scuba Diver in water temperatures of 18.3, 22.2, 25.6, and 29.4 degrees Celsius and to validate the current rates of air consumption listed in popular diving texts. The subjects were nine male volunteers certified as Basic Scuba Divers attending Kansas State University. Mean age of the subjects was 20.55 years, with a mean weight of 73.32 kg, and a mean surface area of 1.92 M^2 . The subjects participated in a fifteen minute underwater activity in which a 46 kick per minute work load was performed while in a semi-seated position breathing through a modified single stage two hose regulator. A polyurethane carboy was modified to collect the expired air and channel it to a Parkinson Cowen Ventilometer for a ten minute period during the underwater activity. The data were analyzed using Analysis of Variance (ANOVA). It was found that with increasing water temperatures there was a significant change in air consumption and the relationship between the two is quadratic. A multiple regression analysis using a quadratic equation for prediction was used to calculate theoretical consumption rates based upon water temperature. Confidence intervals for air consumptions were calculated on the mean data for all water temperatures. Based on these data, it was concluded that water temperature effects air consumption and those rates listed in most diving texts do not apply to this population of divers.