COMPARISON OF THREE HYDROSTATIC WEIGHING METHODS

A Thesis Presented

to

The Graduate Faculty

University of Wisconsin-La Crosse

In Partial Fulfillment

of the Requirements for the

Master of Science Degree

---

by

Joann M. McGarty

December, 1982

ABSTRACT

McGARTY, JOANN M. Comparison of three hydrostatic weighing methods. M. S. in Adult Fitness - Cardiac Rehabilitation, 1982. 6E p. (N. K. Butts)

This study compared hydrostatic weighing (HW) at residual volume (RV), total lung capacity (TLC)-dry and TLC-wet in the determination of body density (BD) and percent body fat (%BF). Considering the comfort of the submerged Ss, it was the aim of this study to establish a HW method which was reliable. Student volunteers included 44 competitive swimmers (25 females; 19 males) and 55 noncompetitive swimmers (31 females; 24 males) ages 17-34. Residual volume was determined by the open circuit nitrogen washout technique. Dry and wet measurements of forced vital capacity (FVC) and TLC were obtained from all Ss to determine appropriate measurement in application to BD and %BF calculations. All Ss underwent HW at RV and TLC. Three BD and %BF were calculated for Ss by applying lung measurements of RV, TLC-dry and TLC-wet. Ss noted method preference; at RV, TLC or neither. A 3 way ANOVA with repeated measures followed by a Scheffé Post Hoc Test was used to analyze the following variables: FVC-dry, FVC-wet, TLC-dry, TLC-wet, BD and %BF by HW at RV, TLC-dry and TLC-wet. A Chi Square analyzed Ss HW method preference. There was a sig ($p < .01$) reduction in FVC-wet and TLC-wet when compared to those measurements dry in Ss combined. There were sig ($p < .01$) diff between HW at RV vs HW at TLC-dry and HW at RV vs HW at TLC-wet ($\bar{x}$ %BF differences = 3.64% and 1.77%, respectively) in Ss combined. %BF with HW at RV > at TLC-wet > at TLC-dry. All subgroups and Ss combined preferred HW at TLC ($p < .05$). The sig diff in HW methods may be due to an underestimation of RV during HW at RV and an overestimation of TLC during HW at TLC-dry. It was concluded that HW is not equivocal at RV, TLC-dry and TLC-wet. HW at TLC-wet may be most accurate in %BF determination. Previous research supports the conclusion that pulmonary air trapping was reduced or eliminated and TLC was truly represented during HW at TLC-wet.

UNIVERSITY OF WISCONSIN-LA CROSSE
College of Health, Physical Education and Recreation
La Crosse, Wisconsin 54601

Candidate: Joann M. McGarty

We recommend acceptance of this thesis in partial fulfillment of this candidate's requirements for the degree:

M. S. in Adult Fitness - Cardiac Rehabilitation

The candidate has completed her oral report.

N K Butts Thesis Committee Chairperson	24 May 1982 Date
Linda K Hall Thesis Committee Member	27 May 1982 Date
Richard A. Fletcher Thesis Committee Member	18 May 1982 Date

This thesis is approved for the College of Health, Physical Education and Recreation.

John C. Mitchem Dean, College of Health, Physical Education and Recreation	May 25, 1982 Date
Howard C. Rose Dean, Graduate Studies	May 25, 1982 Date

ACKNOWLEDGEMENTS

Throughout this year and every year past my father, mother, and brother, Robert, have been a source of constant support in all of my endeavors. Their love and encouragement has instilled the self-confidence necessary for me to achieve success. It is, therefore, with much love and gratitude that I dedicate this thesis to my family.

I would like to express my appreciation for the guidance and knowledgeable resource provided by my Chairperson, Dr. Nancy Butts, and Committee Members, Dr. Linda Hall and Dr. Richard Fletcher. A special thanks to Dr. Butts for the many hours of work spent with me and unending patience.

The Human Performance Lab still echoes with my voice; "keep blowing". I am grateful for having access to all needed equipment employed in this study. Thanks to Jeff Tesch and all HPL employees for their assistance in equipment maintenance.

I would like to thank my housemates:

Anne, Martha, and Suzanne for making the initial phases of school much easier for me;

Barb, John, Jon, Mary Alice, and Patty for their friendship and continuous encouragement this whole year. It's been "great"!

God bless and keep safe all the wonderful friends I have made here in La Crosse.

Joan

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

CHAPTER I

INTRODUCTION

Specific physical characteristics have been identified in people which have enabled them to achieve success in the performance of sports and physical activities. An area of study dealing with one of these physical traits is that of body composition (Karpovich & Sinning, 1971).

Body density and percent body fat, identified as descriptors of body composition, have been used to assess physical fitness and performance levels in the individual (Cureton, Hensley & Tiburzi, 1979). Ideal body fat for college age men and women have been reported to be 12 to 15% and 22 to 25%, respectively (Sloan, 1967; Wilmore & Behnke, 1970; Zuti & Corbin, 1977).

Hydrostatic weighing (HW), with the use of proper equipment, is one of the most popular and accurate techniques of indirectly estimating body density and percent body fat. These measurements are dependent, in part, on the volume of air present in the gastrointestinal tract and the lungs at the time of weighing. Due to the fact that air adds buoyancy, the volume of air must be taken into consideration in the HW process (Thomas & Etheridge, 1980). The ease with which the subject adapts to the water environment during the testing procedure has persisted as a barrier in attaining a precise estimation of percent body fat (Brozek, Grande, Anderson & Keys, 1963).

Need for the Study

It has been established that the determination of body fat and body density by hydrostatic weighing is dependent on lung volume measurements (Brozek, Henschel & Keys, 1949; Welch & Crisp, 1958; Jarrett, 1965; Craig & Ware, 1967; Dahlback & Lundgren, 1972; Bondi, Young, Bennett & Bradley, 1976; Prefaut, Lupi-H & Anthonisen, 1976; Girandola, Wiswell, Mohler, Romero & Barnes, 1977; Robertson, Engle & Bradley, 1978; Thomas & Etheridge, 1980; Weltman & Katch, 1981). Numerous investigators have focused their attention on the development of a HW method using various lung volume measurements. These attempts were made to establish a hydrostatic weighing method which was reliable.

Large lung volumes, including total lung capacity (TLC), have been successfully employed in HW and also appeared to be well tolerated by all subjects tested (Welch & Crisp, 1958; Thomas & Ethridge, 1980; Weltman & Katch, 1981). Two lung volume measurements, residual volume (RV) and forced vital capacity (FVC), which comprise TLC, have been researched during HW. Recent studies reestablished earlier findings that FVC was reduced when tested with the subject immersed in water (Bondi et al., 1976; Girandola et al., 1977; Etheridge & Thomas, 1978). The best representation of the RV of the subject while immersed was determined by a measurement on land since there is a false reading of RV-wet due to air trapping (Dahlback & Lundgren, 1972; Bondi et al., 1976). A more accurate estimation of TLC at the time of weighing, therefore, may be to measure FVC-wet added to RV-dry.

It was the aim of this researcher to consider the comfort of the subject submerged in the water during HW. This researcher was to consider various spirometry measurements least affected by immersion in relationship to the most appropriate choice of methodology in HW procedures.

Statement of the Problem

The problems encountered in this study were threefold:

1. The most accurate measurement of TLC, dry as compared to wet, was to be determined in relation to the estimation of body density and percent body fat by HW.

2. An analysis was to be made comparing the HW results using TLC-wet, TLC-dry and RV.

3. The most comfortable lung volume, TLC or RV, for competitive swimmers and noncompetitive swimmers to perform during HW was to be subjectively determined.

Hypotheses

The following hypotheses were formulated:

1. There are no significant differences in the measurements of TLC-dry and TLC-wet or FVC-dry and FVC-wet in male and female competitive swimmers and noncompetitive swimmers.

2. There are no significant differences in the estimation of body density and percent body fat by HW using lung volume measurements of TLC-dry, TLC-wet or RV in male and female competitive swimmers and non-competitive swimmers.

3. There is no significant difference in preference of lung volume utilized in HW by male and female competitive swimmers and noncompetitive swimmers.

Delimitations

In reference to this study, the following delimitations were made:

1. The population studied were delimited to male and female college students, competitive swimmers and noncompetitive swimmers, ages of 17-34 years who attend the University of Wisconsin-La Crosse.

2. Participants were required to fast and abstain from smoking for 12 hours prior to scheduled testing.

3. All subjects were to be free of respiratory disease and acute pulmonary symptoms.

4. Vigorous physical activity was avoided five hours prior to hydrostatic weighing.

5. To avoid fluid retention during menstruation, females were tested approximately seven days prior to or after their cycle.

Limitations

The application of the following limitations must be observed in relation to this study:

1. The subjects were volunteers, therefore, a random sample did not exist.

2. There was a relatively small number of subjects (N = 6) selected for the pilot study to determine reliability of the proposed methodology of hydrostatic weighing.

3. This study was limited to describing the attitudes of the selected groups.

4. The degree of adaptation to a water environment may have been varied in the noncompetitive swimmer group.

5. It was difficult to determine if the breathing maneuvers mandated in the testing were performed correctly.

6. A learning process may have occurred during the testing procedure.

Assumptions

The following assumptions were made in relation to the scope of this study:

1. All subjects performed the necessary respiratory function tests to the best of their ability.

2. All subjects fasted and refrained from smoking for 12 hours prior to testing.

3. All subjects avoided vigorous physical activity five hours prior to testing.

4. The attitudinal response concerning testing methods was answered honestly and to the best ability of each subject.

5. The six liter and 13.5 liter spirometers measured volume equally.

Definition of Terms

Archimedes Principle - a body submerged in a fluid is buoyed up by a force equal to the weight of the fluid displaced.

Body Plethysmograph - an airtight box encloses the entire body of the subject and measures gas volume and pressure changes in the system produced by breathing.

Closing Volume - the terminal portion of a slow exhaled vital capacity that indicates the point at which the most gravity-dependent airways start to collapse (Kacnarek, Dimas & Mack, 1979, p. 207).

Competitive Swimmer - a person who is trained in the performance of swimming, is a member of the University of Wisconsin-La Crosse swim team, and has mastered the art of rhythmic breathing.

Density - the mass per unit volume of a body (D = M/V), expressed as gm/cc.

Forced Vital Capacity (FVC) - the maximum volume of gas that can be forcefully exhaled after a maximal inspiration.

Hydrostatic Weighing (HW) - a technique used to calculate percent body fat through total submersion of the subject to attain body volume based upon Archimedes Principle.

Lung Volume or Capacity-dry - that specified lung volume or capacity measured on land.

Lung Volume or Capacity-wet - that specified lung volume or capacity measured in water with the subject immersed in water to neck level.

Noncompetitive Swimmer - a person who may not swim at all or who is untrained in swimming. The individual has never been a member of a swim team and has not completed the level of Advanced Life Saving according to the American Red Cross.

Percent Body Fat - that percentage of total body weight which is composed of adipose tissue as determined by HW and the percent body fat formula (Brozek, Grande, Anderson & Keys, 1963).

Residual Volume (RV) - the amount of gas remaining in the lung after a maximal expiration.

Spirometer - a device which measures exhaled or inhaled air volume per unit time.

Total Lung Capacity (TLC) - the volume of gas contained in the lung at the end of a maximum inspiration.

CHAPTER II

REVIEW OF RELATED LITERATURE

Introduction

Hydrostatic weighing has been established as a successful means used by many investigators to estimate body density and percent body fat (Katch, Michael, & Horvath, 1967). Improvements in technique have been made, as the control of intervening variables were studied. Factors influencing HW results include air in the lungs and gastrointestinal (GI) tract at the time of weighing. Much controversy still exists among researchers in this field relative to the effect of these influencing factors in relation to the most precise determination of body fat and density (Weltman & Katch, 1981). The results of studies pertaining to those factors involved in HW will be discussed in this chapter.

Hydrostatic Estimation of Body Density and Percent Body Fat

The calculation of the proportion of fat to other tissues in the body has been achieved through the measurement of body density. Archimedes Principle defines body density as the relationship of body weight per unit volume. The principle states that a body submerged in a fluid is buoyed up by a force equal to the weight of the displaced fluid (Behnke, 1961). The application of the Archimedian Principle of water displacement has been used in hydrostatic weighing for the determination of body density and percent body fat.

Investigation by Goldman and Buskirk (1961) led to the derivation of a body density formula. The weight of the displaced water was equal to the difference between the weight of the body in air and the weight when submerged. They indicated that a correction factor was needed for the density of water displaced by the body. They also recommended that the water temperature be close to that of body temperature (35-36^{o}C). In recording the water temperature and applying the relating density value, the following equation was derived:

$$D = \frac{M_A}{\frac{M_A - M_W}{D_W}} \qquad \text{equation (1)}$$

where:

D = Density of body

M_A = Mass of body in air

M_W = Mass of body in water

D_W = Density of water (Goldman & Buskirk, 1961)

Assuming the derived equation was correct, the accuracy of HW methods depended on the ability to determine or limit the volume of air in the gastrointestinal (GI) tract and to assess the volume of air present in the lungs at the time of underwater weighing. These gases add buoyancy to the body and if unaccounted for will underestimate body density (Thomas & Etheridge, 1980). On the basis of the findings of Bedell, Marshall, DeBois, and Harris (1956), the value of 100 ml. (BTPS) can be used in the equation to correct for air in the GI tract. This is done in order to provide a more valid estimation of body density on the average. The amount of air in the GI tract varies in each

individual but it should not exceed 100 ml. if the subject is weighed after fasting for 12 hours (Goldman & Buskirk, 1961).

The remaining gas in the lung was determined and applied to the formula for body density. Although controversy existed concerning RV as the best suited lung volume measurement, RV and the GI air volume were applied to the formula which stated:

$$D = \frac{M_A}{\frac{M_A - M_W}{D_W} - RV - .1\ L.} \qquad \text{equation (2)}$$

(Buskirk, 1961)

Conversion of Body Density to Percent Body Fat

Several formulas exist for predicting percent body fat from the calculated body density. Due to the inability of researchers to agree on the exact density of lean body mass and adipose tissue, the formulas are slighly varied. Four popular formulas are presented.

Rathburn and Pace (1945) explored the fat content of guinea pigs and determined the specific gravity of fat and fat free tissue to be 0.918 and 1.0, respectively. The following formula was derived:

$$\% \text{ Fat} = \left(\frac{5.548}{\text{specific gravity}} - 5.044\right) \times 100 \qquad \text{equation (3)}$$

Keys and Brozek (1953) criticized the derivation of the specific gravity values used in determining the formula by Rathburn and Pace in 1945. After studying the density of fat in men, women and various animals, Keys and Brozek (1953) reported a density value of 0.90074 for human fat at 36°C. This information enabled the development of the following formula for predicting fat percentage in humans:

$$\% \text{ Fat} = \left(\frac{4.201}{\text{body density}} - 3.813\right) \times 100 \qquad \text{equation (4)}$$

Later Siri (1961) stated that a fat-free body should be used in the development of a conversion formula. He determined the values of 1.100 lean body mass and 0.900 fat would be employed in the development of his formula:

$$\% \text{ Fat} = \left(\frac{4.95}{\text{body density}} - 4.50\right) \times 100 \qquad \text{equation (5)}$$

In 1963, Brozek, Grande, Anderson and Keys established a more accurate estimation of body composition through analysis of body compartments and chemical components. Their research replaced the "reference man", for whom fat content was assumed, with a "reference body" of known composition. Chemical analysis of three male cadavers was used in defining the "reference body" with a density of 1.064. These researchers also used new information concerning the density of "cell residue" which is free of fat and extracellular water. This enabled a more correct partition of "obesity tissue" and a better estimate of fat content. They computed a fat density of 0.915. Applying this new information to a body fat formula resulted in the following:

$$\% \text{ Fat} = \left(\frac{4.570}{\text{body density}} - 4.142\right) \times 100 \qquad \text{equation (6)}$$

In spite of the disagreement between researchers, a high correlation of 0.995-0.999 exists between the formulas predicting percent body fat even though the actual values vary (Wilmore & Behnke, 1969). The formulas most often applied in recent research are equations 5 and 6 by Siri (1961) and Brozek et al. (1963), respectively.

According to Siri (1961) the standard deviation of $\pm$ 4% represents the error in predicting percent body fat by HW. This percentage of error

may be due to technical difficulties in measuring body density. Normal variability in body constituents and the uncertainty in establishing the compositions of adipose tissue also contribute to the percentage of error. Predicting percent body fat is also limited by the "reference man" representing true averages for the subjects to be tested. An additional source of error may be from the determined residual volume used in the HW calculations.

Lung Volumes Influencing HW Results

The largest debatable factor has remained in the area of assessing the appropriate volume of air in the lungs during HW to ascertain the most accurate measurement of body density and percent body fat. The hydrostatic pressure effect on various lung volumes has been studied. The suitable method and place of measurement, dry versus immersed, are also factors which have been analyzed. Speculations have been made, based on the literature, with regard to the most comfortable lung volume performed in the HW process (Weltman & Katch, 1981).

Residual Volume (RV)

It has been determined that the accuracy of HW is dependent on the appropriate lung volume measurement. Due to the increase in pressure applied to the thorax when immersed in water, as is the case in HW, significant increases and decreases have been found in lung volumes and capacities (Carey, Schaefer & Alvis, 1956; Jarrett, 1965; Agostoni, Gurtner, Torri & Rahn, 1966; Craig & Ware, 1967; Hong, Cerretelli, Cruz & Rahn, 1969; Prefaut et al., 1976; Robertson et al.,

1978). Residual volume was indicated as being the least affected by hydrostatic pressure and is easiest to reproduce in and out of the water (Welch & Crisp, 1958; Girandola et al., 1977). As a result of these findings RV has been employed as standard practice in HW procedures.

Studies comparing RV-dry and RV-wet reported conflicting results. Changes in RV as a result of water immersion would affect the calculations of body density as measured by HW. A number of findings have indicated that RV decreased 4-17% when measured immersed (Brozek et al., 1949; Jarrett, 1965; Agostoni et al., 1966; Bondi et al., 1976; Robertson et al., 1978; Sawka, Weber & Knowlton, 1978). Other investigators have found no significant changes in RV when immersed (Carey et al., 1956; Craig & Ware, 1967; Prefaut et al., 1976). In contrast, Girandola et al. (1977), has indicated that RV increased by 6.7% when measured immersed. Although the results of Carey et al. (1956), were not statistically significant, a 5% increase in RV was observed in the water. Lawther (1969) found a significant increase (221 mL) in RV in the water with a group of subjects similar in age to those used in this research study.

Several reasons for the decrease in RV have been proposed. There is an increase in intrathoracic fluid as there is a central blood shift imposing a restriction for lung expansion (Jarrett, 1965; Bondi et al., 1966). An increase of 20 cm H_2O pressure is applied to the thorax when immersed to neck level (Craig & Ware, 1967). The diaphragm and abdominal contents are displaced towards the head when

the individual is immersed (Dahlback & Lundgren, 1972). These factors may reduce RV in the water by direct compression. Numerous researchers (Agostoni et al., 1966; Dahlback & Lundgren, 1972; Bondi et al., 1976; Robertson et al., 1978) mentioned that false readings of a decrease in RV may be due to airway closure resulting from pooling of blood in the thorax. This pooling of the blood is thought to cause a swelling of blood vessels which then narrows the airways. Measurements of RV by gas dilution were lower than the actual volume in the lung. The collapsing airways inhibited complete gas mixture and impeded air from exiting the lungs (Dahlback & Lundgren, 1972; Bondi et al., 1976; Robertson et al., 1978). With this in mind, Robertson et al. (1978) suggested that RV measured on land may be a more accurate representation of actual RV during immersion.

An increase in RV-wet as measured by Girandola et al. (1977) was found secondary to "stiffness" of the lung tissue caused by pulmonary vascular engorgement. This pulmonary congestion also caused increased air trapping raising RV (Dahlback & Lundgren, 1972).

Prefaut et al. (1976) and Robertson et al. (1978) concluded that RV was not changed by immersion. According to these researchers, hydrostatic pressure which tends to decrease RV is counterbalanced by the vascular congestion that tends to increase RV during immersion.

Methodology of measuring RV has also been suggested as a possible explanation for observed differences. Some investigators using the same methods of measuring RV still reported conflicting results (Girandola et al., 1977). Using the open-circuit nitrogen dilution

method to determine RV in the water, Brozek et al. (1949) found decreases in RV while Lawther (1969) reported substantial increases in RV. Similar conflicting data were reported using the 3-breath nitrogen dilution method (Carey et al., 1956; Agostoni et al., 1966). Observing the inconsistent reports, it was concluded that the technique of measuring RV was not the cause of the discrepancy (Girandola et al., 1977).

Closing Volume (CV) and Pulmonary Air Trapping

Closing volume, an indicator of airway collapse and subsequent air trapping, was shown to be significantly increased (41.3%) by adding and removing tourniquets to the limbs during immersion. These findings indicated that blood flow to the thorax result in increased closing volume and air trapping (Bondi et al., 1976). Robertson et al. (1978) determined that air trapping was responsible for the 200 ml. difference in RV measured immersed by gas dilution and plethysmography. Air trapping is also known to be more pronounced in old age (Anthonisen, Dannon, Robertson & Ross, 1969).

Closing volume was measured at different lung volumes in an attempt to indicate that volume which eliminated air trapping, when measured immersed, as a limitation in HW results (Dahlback & Lundgren, 1972). These investigators showed that when immersed in water, 148.5 ml. (3.3% of VC) was the amount of air trapped in the lungs measured at RV plus 5% of VC. Residual volume plus 12% of VC resulted in 1.8% of VC air trapping. The most significant outcome was the measurement at RV plus 20% which produced only 1.1% of VC air trapping. These researchers

determined that air trapping would not be eliminated until lung volumes increased.

Forced Vital Capacity

Considering the use of a larger lung capacity in the HW procedure, FVC was reviewed. Forced vital capacity, which constitutes approximately 80% of TLC (Kacmarek, Dimas & Mack, 1979) showed no significant change when measured immersed by Carey et al. (1956) and Hong, Ting and Rahn (1960). Further research supported evidence to the contrary and found FVC to decrease significantly by 260 ml. (90-95%) when measured immersed (Craig & Ware, 1967). Similar results found by others, were attributed to the hydrostatic pressure, equivalent to 20 cm H_2O, limiting maximum inspiration (Agostoni et al., 1966; Hong et al., 1969; Dahlback & Lundgren, 1972; Bondi et al., 1976; Prefaut et al., 1976). Blood shift of 700 ml. into the thorax has been estimated as the predominant factor for reduction of FVC during immersion (Agostoni et al., 1966; Hong et al., 1969). This view was also supported by Robertson et al. (1978).

Total Lung Capacity

The total lung capacity (TLC) measurement is influenced by findings concerning RV and FVC as it is the sum of the two. The problem of pulmonary air trapping, which occurs when performing RV in the water, can be reduced and possibly eliminated with the substitution of large lung volumes (Dahlback & Lundgren, 1972; Thomas & Etheridge, 1980).

Subsequently, the most recent study used TLC-dry as the lung volume measurement of choice in HW (Weltman & Katch, 1981). Results

showed that body composition parameters were significantly different between HW at RV and HW at TLC-dry. Although results were statistically significant, HW at RV and TLC-dry were negligible as the results were within the measurement error associated with the HW technique (Brozek et al., 1963). Total lung capacity has been recommended as the method of choice because dependability was achieved and a low level of discomfort in performance by the subjects was observed. The suggestion was made that TLC-wet may increase the accuracy of the HW technique (Weltman & Katch, 1981).

Methods of Measuring Lung Volumes

Spirometry

The spirometer is a tool which simply and accurately measures forced vital capacity (FVC). Although there are many physiological measurements available from spirometry, for clinical purposes the most useful measurement was found to be the forced expiratory spirogram (Sheen & Sly, 1980; Burki, 1981).

Gas Dilution Techniques

The helium dilution and nitrogen washout techniques have been reported to be reliable indirect methods to measure TLC and RV in subjects who did not have evidence of airway obstruction (Wilmore, 1969; McBride & Wohl, 1979). These techniques are dependent upon normal distribution of ventilation in the lungs. Residual volume and TLC may be underestimated when airway obstruction is present. These methods were particularly useful for those unable to understand or cooperate with plethysmography (McBride & Wohl, 1979).

Wilmore (1969) determined that the indirect method of open-circuit nitrogen washout, being valid and reliable, substantially reduced the time necessary for a single RV determination. The subjects breathe 100% oxygen at approximately two-thirds of their maximal capacity which allows for a greater exchange and mixing of the gases within the lungs. The total of 6-8 breaths are needed for a nitrogen equilibrium to be attained between the breathing bag and the lungs. Nitrogen concentrations are recorded at initiation, equilibrium and termination of the breathing period. These concentrations are used in the formula to calculate RV. This technique makes it possible for duplicate RV determinations in a short period of time.

Many studies involving the measurement of lung volumes immersed in water versus land have been performed (Brozek et al., 1949; Welch & Crisp, 1958; Girandola et al., 1977; Weltman & Katch, 1981). The majority of these studies used the nitrogen washout technique over the helium dilution technique (Agostoni et al., 1966; Wilmore, 1969; Dahlback & Lundgren, 1972; Prefaut et al., 1976; Girandola et al., 1977; Weltman & Katch, 1981).

Body Plethysmograph

This method requires the subject to be sealed in an airtight chamber which is connected to a spirometer. The subject breathes to the outside of the box through a mouthpiece. The TLC and RV is calculated by measuring the change in pressure at the mouthpiece and the volume which the thorax expanded. The chest expansion is measured as an increased plethysmograph volume. Plethysmography has been established as the most accurate in the determination of TLC and RV in the presence

of airway obstruction. This method was used in the determination of closing volume and pulmonary air trapping when lung volumes were measured immersed, because it can detect any amount of trapped air. In comparison, the helium dilution and nitrogen washout techniques were shown to be insensitive to a small volume of trapped gas which caused a false low reading of RV (Robertson et al., 1978).

Lung Volume Method Preferred by Subjects

Submersion in HW has been observed to have a psychological effect in some individuals (Brozek et al., 1949). There was a moderate degree of anxiety inhibiting exhalation. This was noted as a factor determining the effect of submersion on residual air volume.

Welch and Crisp (1958) suggested that in determining body density by HW with untrained subjects, measurements taken with the lungs entirely filled with air would be preferable. This method would appear to eliminate the psychological effect observed by Brozek et al. (1949). The subject would be more at ease and the tester would have more time to obtain the underwater weight which eliminates some of the inaccuracy that occurs with untrained subjects.

Since recent studies revealed larger lung volumes to be appropriate in HW, a practical standpoint was taken by researchers when they suggested using larger lung volumes after observing the subjects they tested. There was less scale fluctuation and the number of trials to obtain hydrostatic weight were reduced with the reliability from ten trials with RV to only three trials with TLC (Weltman & Katch, 1981).

Methods of Hydrostatic Weighing

Hydrostatic weighing at RV and TLC have been discussed. Other methods have been used by researchers and are reviewed.

Snorkel Breathing

Katch et al. (1967) underwater weighed subjects using a common swimming snorkel with mouthpiece to allow for breathing while submerged until the subjects were relaxed and little movement of the scale was observed. Underwater weight was taken following maximal exhalation and held for about 5 seconds.

RV Plus 1 Liter

Jensen (1979) weighed children underwater at the level of RV plus one liter of air. The subjects performed a maximal exhalation into a mouthpiece attached to a two-way stopcock prior to submersion. A small rubber breathing bag holding one liter of air was attached to the stopcock. After exhaling maximally the subject was allowed to inhale the one liter of air and submerge.

Breathing Valve

Hydrostatic weighing was performed at functional residual capacity (FRC) and RV using a specialized valve attached to a spirometer (Thomas & Etheridge, 1980). The subject was able to breathe room air through the valve while submerged. When the test began, the valve was turned into the attached spirometer. The subjects' normal respirations were monitored to establish FRC and 3 to 5 trial weights were recorded. The subjects then exhaled through the valve maximally and weight was recorded at RV.

Conclusion

Body density and percent body fat have been used in the assessment of physical fitness levels in men and women. Formulas have been derived in calculating these components which incorporated recording body weight by hydrostatic weighing. This measurement was found to be dependent on the amount of air in the lungs at the time of HW. Two areas of controversy continue to be: 1) the appropriate and/or accurate volume to use; and, 2) whether that volume was to be measured on land or immersed.

Most authors have agreed that lung volume measurements differ when measured on land and in the water. The effect of water immersion produces pulmonary air trapping at the RV level. Air trapping is eliminated at larger lung volumes. This might indicate a measurement of RV to be performed on land. To assure accurate HW results, air trapping must be minimized if not eliminated. Recent literature has indicated that larger lung volumes used in HW, rather than smaller volumes, reduced air trapping significantly. The appropriate measurement of large lung volumes may be best represented at HW when measured immersed.

Hydrostatic weighing at larger lung volumes, such as TLC, may reduce anxiety in the untrained subjects. The subjects may feel more comfortable with HW at TLC than at RV. A more accurate reading may be taken by the tester with the decreased scale fluctuation at TLC.

CHAPTER III

METHODS

Introduction

The subjects employed in this study are described according to age and physical characteristics. Testing procedures are explained for all measured variables. The statistical treatment of all collected data are discussed in this chapter.

Subject Selection

A total of 44 competitive swimmers (25 females; 19 males) and 55 noncompetitive swimmers (31 females; 24 males) volunteered to establish the reliability of HW at TLC-wet. These subjects ranged in age from 17-34 years and were students at the University of Wisconsin-La Crosse. Prior to testing, subjects were asked if they were suffering from any acute or chronic respiratory illnesses. Those complaining of acute symptoms were rescheduled for testing at a later date. One subject suffered from chronic respiratory disease, asthma, and was eliminated from the study. At the time of testing, all subjects were considered to be in good health and free of any respiratory afflictions.

To establish the lung volume technique as preferred by subjects as well as the most accurate for determination of body density and percent body fat, it was necessary to select individuals who were well adapted to the water environment as well as those who were not. For

this reason two groups, competitive swimmers and noncompetitive swimmers, were formed to subjectively analyze testing styles. The competitive swimmers were members of the university swim team and the noncompetitive swimmers were either unable to swim or were lower level swimmers with the inability to compete. Participants were randomly assigned to the order of lung volumes performed, RV and TLC, during the HW procedures. The subjects were informed of all procedures and potential hazards. An informed consent statement was signed by all subjects prior to any testing (see Appendix A).

Instrumentation and Procedures

Pilot Study

A pilot study (N = 6) was conducted to determine the test-retest reliability of the HW at TLC-wet. Subjects were similar in physical characteristics to the subjects in this study. Results of this pilot study are included in Chapter IV.

Spirometer Calibration

Two spirometers, a six liter Collins Vitalometer (model number P-600) and 13.5 liter Collins Respirometer (model number 2136) were used in calibrating the RV apparatus and measuring FVC, respectively. The spirometers were filled with water until the level registered halfway up on the water level gauge. The investigator introduced a known volume of air, four liters, from the six liter spirometer into the 13.5 liter spirometer via connecting tubing. Four liters of air also registered on the 13.5 liter spirometer indicating calibration between the two spirometers when water levels were accurate.

Residual Volume

The RV was determined through indirect analysis by the open-circuit nitrogen washout technique (Wilmore, 1969). Residual volume apparatus is pictured in Figure 1.

The six liter spirometer was employed in measuring the volume of oxygen to be used during the trials to determine RV. Ten sample volumes were introduced into the spirometer at a 4.6 second setting time for calibration purposes. This volume of pure oxygen was then introduced into a five liter rubber breathing bag by opening a two-way stopcock valve located at the base of the spirometer. With the bag vacuum free of air, the oxygen passed through the valve into the bag filling it with the calculated volume. The breathing bag was then mechanically vacuumed of all gas contents. The flushing of 100% oxygen followed by vacuuming of the bag contents was performed 2-3 times to assure the purest concentration of oxygen possible. After this procedure the valve to the oxygen equipment was closed.

A Collins Introgen Analyzer (model number 21232) continuously monitored the percent of nitrogen in the inspired and expired air. The analyzer was placed at the distal end of the rubber bag between the two-way breathing valve and subject's mouthpiece. The resolution of this system was 0.1% nitrogen with a readout accuracy of 0.1% nitrogen.

The intent and testing procedures were first explained to the subject. The subject was to perform the breathing maneuvers to the best of his/her ability. It was emphasized that the effort put forth was important in gaining proper readings of RV which affect the estimation of body fat. The test was administered in the sitting position

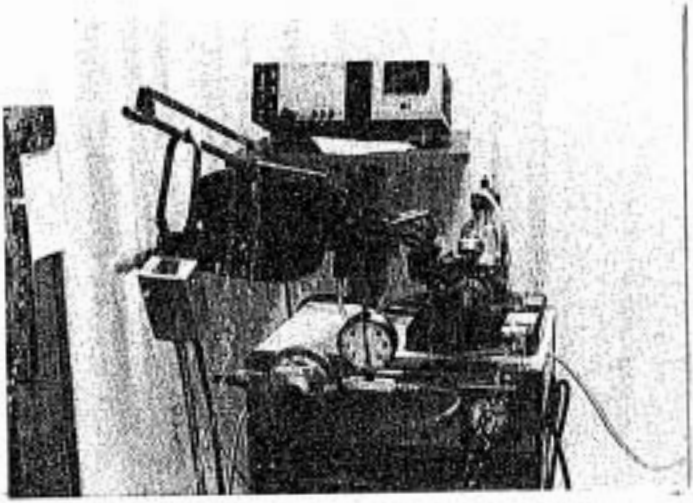

Figure 1. Residual Volume Apparatus

on land similar to the position assumed in the HW procedure. After assuming the sitting position, nose clips were secured on the nose and a mouthpiece was placed in the mouth of the subject making a tight seal. After three or four normal breaths with the valve open to room air, the subject was instructed to inhale deeply and then fully exhale. At this point he/she was to tap the tester's hand which was located on the two-way valve. Immediately the initial alveolar nitrogen concentration (AN_2) was noted and the valve was closed to connect the subject with the breathing bag filled with oxygen. The nitrogen concentration in the oxygen was again recorded after the subject's first breath from the bag (IN_2). This denoted the impurity of the oxygen.

The subject was then instructed to inhale and exhale at about two thirds of his/her maximal volume, at a rate of one breath every three seconds. The tester made visual observation of the continuously decreasing oscillations in the nitrogen percentage of the inspired and expired air. This allowed for a fairly precise estimation of the establishment of a concentration equilibrium. This was attained after 5-10 breaths and recorded as the midpoint between the equilibrium range (EN_2).

At this point, the subject was told to immediately take a maximal inspiration followed by a maximal expiration. The subject indicated the point of maximal expiration by tapping the tester's hand located on the two-way valve. The percent of nitrogen at this point was then recorded (FN_2).

After two minutes of normal respiration followed by a minute of moderate hyperventilation the subject repeated the entire procedure.

The trial best performed by the subject was used in body density calculations. If there was a difference of greater than 60 mls. between trials a third trial was performed. The highest value of the two closest trials was used. Residual volume was calculated by the formula cited by Wilmore (1969) presented in Appendix B.

Total Lung Capacity Dry and Wet

Total lung capacity dry and wet were obtained by first attaining the FVC on land and again immersed in water to the neck level. These results then added to the RV previously calculated TLC-dry and TLC-wet at BTPS. A Collins 13.5 liter Respirometer (model number 2136) was used to record three trials of FVC-dry and three trials wet.

The intent and purpose of the FVC tests were explained to the subject. Again it was stressed that it was important for the subject to put forth the best effort possible to assure the best results. The test was performed in the seated position on land and again in the water. A stabilized chair was necessary in supporting the subjects during the immersion measurement.

The subject was seated at the spirometer with a nose clip secured to the nostrils and a mouthpiece that was connected to the spirometer was placed in the mouth. A tight seal was made with the lips around the mouthpiece. At this point, the subject was instructed to inhale as deeply as possible and, when a maximal inspiration was reached, a rapid and complete exhalation was made. Encouragement was given to continue blowing air out as long as possible. Upon completion the subject was given a rest period of up to 2-3 minutes between the three trials. A

vertical line drawn by the spirometer indicated the volume of air which displaced the spirometer drum. The length of the line was converted to a calculated value of FVC (Kory, Callahan & Boren, 1961; Morris, Koski & Johnson, 1971). The maximum value attained was the FVC recorded.

Hydrostatic Weighing

Body density and percent body fat were assessed by HW. Each subject was weighed on a Continental Health-O-Meter scale (model number 400DLK) on land and weighed underwater in a 4' x 4' x 4' S.S. Hydrotesting Tank (model number 09771) on a Chatillon autopsy scale (model number 8-2096) accurate to 25 grams. Water temperature was maintained between 33° and 35° C.

Subjects were weighed by two different methods of HW. One method used RV and the other used TLC for the determination of body density and percent body fat. Subjects were randomly assigned to the order of HW method to be performed. The subject's weight was assessed by both methods in 3-10 trials until 3 identical recordings were obtained in succession (Katch et al., 1967; Weltman & Katch, 1981). This value was used as an estimate of the underwater weight for body density determination.

The subject entered the water tank by the ladder and assumed a comfortable sitting position. Instruction was given to rid air trapped in swimming apparel. A weighted belt was placed across the lap of the subject. Nose clips were secured to the nose. Emphasis was placed on performing the respiratory maneuvers to the best possible ability.

Subjects were asked to move slowly while sitting in the chair to decrease scale fluctuation due to buoyancy. Holding onto the sides of the seat for support, the subject was instructed to inhale then exhale as much air as possible. When this point was reached, the subject bent slowly forward and completely submerged in the water. Breath was held until the signal, a knock on the tank, was given by the tester to bring his/her head above water and rest. This terminated one trial of HW at RV. Ample rest time was provided between trials until 3 identical weights were recorded in succession.

The TLC method of HW was achieved by asking the subject to inhale maximally before submerging. The subject bent slowly forward and completely submerged under the water. The breath was held again until the same signal, a knock on the tank, was given by the tester to come above water and rest. This terminated one trial. Ample rest time was provided between trials until 3 identical weights were recorded in succession.

The weight of the chair with the weighted belt, measured by the scale reading prior to testing, was subtracted from the observed weight. Recordings were made on the data collection sheet (see Appendix C). Three values of percent body fat and three values of body density were calculated from a standard formula (Brozek et al., 1963) by application of lung measurements RV, TLC-dry and TLC-wet. An ample rest period of 3 or more minutes was individually determined and separated the two methods tested.

Subjective Evaluation of Methods

At the completion of all testing, the subject was asked to respond to a question truthfully and to the best of his/her ability. He/she was asked to state which hydrostatic weighing method was most comfortable and preferred; the RV or the TLC method. He/she could also respond with no preference between methods. The subject indicated his/her response in writing on a sheet of paper. He/she also was asked to state a reason for his/her preference.

Statistical Treatment of Data

Standard descriptive techniques were used to describe the subjects. A 2 x 2 x 3 ANOVA with sex, group and method was used to analyze collected data on body density, percent body fat, FVC and TLC. A Scheffé Post Hoc further analyzed these data. Chi Square analyzed subjective preference of methods.

CHAPTER IV

RESULTS AND DISCUSSION

Introduction

The purpose of this study was to determine if the technique of HW at TLC was equivocal to HW at RV in the determination of body density and percent body fat. The study also was to differentiate between the measurements of FVC-dry and FVC-wet as components of the TLC hydrostatic weighing technique. Also, it was of interest to ascertain if body density and percent body fat measurements differed between sex, method of HW and subject group. In addition, personal preference of HW method was tabulated for each subject. This chapter includes statistical analyses of the data collected from the HW techniques and lung volume measurements. A discussion of the possible factors which influenced the body density, percent body fat and lung volume results is also included in this chapter.

Subjects

The subjects involved in this study were 25 female and 19 male competitive swimmers; 31 female and 24 male noncompetitive swimmers whose physical characteristics are described in Table 1. The two different groups and sexes were chosen to determine if HW at TLC-dry or wet was equivocal to the RV method of HW for each subgroup. These subjects, representative of many levels of swimming ability, also indicated their method of preference for HW.

Table 1. Mean and standard deviations for age and physical characteristics of 99 competitive and noncompetitive swimmers.

Subject Group	Sex	N	(yrs)	Height (cm)	Weight (kg)
Competitive Swimmers	F	25	19.2[a] 1.52[b]	168 6.7	63.88 9.704
Noncompetitive Swimmers	F	31	22.0 3.16	164 6.6	58.12 7.330
Competitive Swimmers	M	19	19.4 1.07	180 7.4	74.41 7.715
Noncompetitive Swimmers	M	24	21.3 2.25	177 6.9	74.74 10.642

[a]Means
[b]Standard Deviations

Pilot Study

A Pearson Product Moment Correlation was used to determine the test-retest reliability coefficients of RV, FVC-dry, FVC-wet, TLC-dry, TLC-wet, body density and percent body fat measurements during a pilot study (N = 6) prior to actual data collection. Three measurements of body density and percent body fat were obtained by the methods of HW at RV as described by Goldman and Buskirk (1961), and HW at TLC as described by Weltman and Katch (1981) with application of TLC-dry and TLC-wet. The correlations for all measurements were as follows: $r = 0.90$ for RV, $r = 0.99$ for FVC-dry and TLC-dry, $r = 0.98$ for FVC-wet and TLC-wet, $r = 0.99$ for body density and fat by HW at RV, $r = 0.97$ for body density and fat by HW at TLC-dry and TLC-wet. Correlations

were high which may be partially due to the actual procedure and measurements as well as to the degree of expertise which this researcher acquired from previous experience in hydrostatic weighing. Regardless of reason, the techniques were shown to be reliable.

Lung Volume Measurements

The means and standard deviations of RV, FVC-dry, FVC-wet, TLC-dry and TLC-wet for all subjects are reported in Table 2.

Residual volume was measured on land as suggested by Robertson et al. (1978). Studies indicate an inaccuracy in RV when measured during immersion (Agostoni et al., 1966; Dahlback & Lundgren, 1972; Bondi et al., 1976; Robertson et al., 1978). It was determined that premature airway closure causing air trapping occurs when performing RV maneuvers while immersed. Measurements taken during immersion are not considered to be accurate due to the collapsing airway impeding the necessary mixture of gases for analysis and preventing air from exiting the lungs on exhalation (Bondi et al., 1976; Robertson, et al., 1978). This indicates that RV, when performed during immersion, may actually be underestimated and influences the determination of body density and percent body fat by HW at RV.

In referring to Table 2, Figure 2, and Appendix D, comparisons were made of FVC and TLC measurements both dry and wet for all subject groups. Computer analysis of this data, recorded in Table 3, revealed no significant differences ($p > .05$) between sex and subject group, method and subject group or method, subject group and sex for FVC and TLC measurements. There were significant differences in FVC between subject groups

Table 2. Means and standard deviations of lung volume measurements.

Subject Group	Sex	N	RV (L)	Forced Vital Capacity (L., BTPS) Dry	Wet	Diff.	Total Lung Capacity (L., BTPS) Dry	Wet	Diff.
Competitive Swimmers	F	25	0.986 0.183	4.508 0.786	4.237 0.701	0.271	5.492 0.770	5.221 0.690	0.271
Noncompetitive Swimmers	F	31	1.065 0.234	4.108 0.478	3.910 0.450	0.198	5.174 0.553	4.975 0.527	0.199
Total Females	F	56	1.030 0.258	4.287 0.659	4.056 0.593	0.231	5.316 0.671	5.085 0.612	0.231
Competitive Swimmers	M	19	1.230 0.166	6.089 0.833	5.760 0.832	0.329	7.319 0.858	6.989 0.858	0.330
Noncompetitive Swimmers	M	24	1.316 0.413	5.692 0.653	5.326 0.690	0.366	7.009 0.839	6.642 0.814	0.367
Total Males	M	43	1.278 0.327	5.868 0.755	5.517 0.739	0.351	7.146 0.851	6.796 0.842	0.350
Total Combined	M+F	99	1.150 0.310	4.973 1.052	4.691 0.981	0.282	6.111 1.181	5.828 1.113	0.283

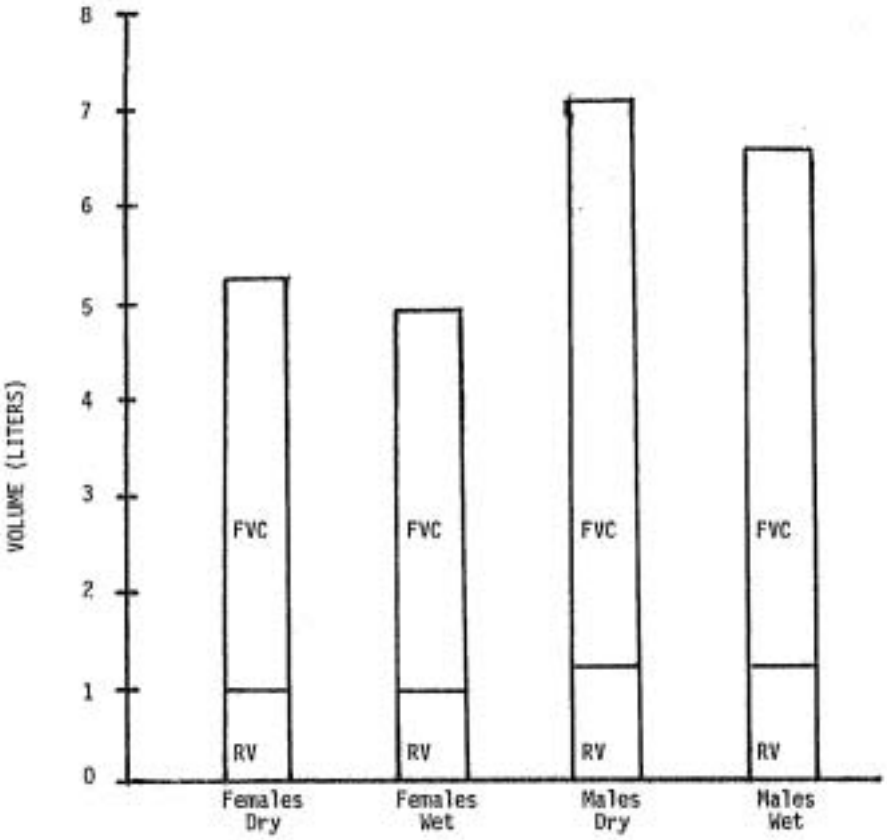

Figure 2. Total lung capacity measurements for males and females (L. at BTPS).

($p < .01$) and sexes ($p < .001$); in TLC between subject groups ($p < .05$) and sexes ($p < .001$). Most interestingly, a significant difference ($p < .001$) was found between method of measurement and sex for FVC and TLC volumes.

Table 3. Statistical analysis of variance for lung volume measurements.

Variable	Comparison*	F Ratio	Level of Significance
FVC	Competitive vs Noncompetitive	8.48	.01
	Male vs Female	130.21	.001
	Sex vs Group	0.04	NS
	Method vs Group	0.29	NS
	Method vs Sex	11.95	.001
	Method vs Group vs Sex	2.84	NS
TLC	Competitive vs Noncompetitive	4.27	.05
	Male vs Female	143.95	.001
	Sex vs Group	0.02	NS
	Method vs Group	0.29	NS
	Method vs Sex	12.00	.001
	Method vs Group vs Sex	2.83	NS

*$df_{1,95}$

To determine where the significance lay between methods and sex, a Scheffé post hoc analysis was performed (see Table 4). There was a mean decrease of 231 ml. in females' FVC-wet and TLC-wet when compared

to FVC-dry and TLC-dry. The difference in lung volume measurements was significant ($p < .01$). These decreases were equivalent to reductions of 5% in FVC and 4% in TLC. The males showed a significant ($p < .01$) decrease in FVC-wet and TLC-wet when compared to FVC-dry and TLC-dry, respectively. The average reduction in FVC amounted to 351 ml. which is equivalent to 6%. These results also equal a 5% reduction in TLC at 350 ml. Combining all subjects, there was an overall reduction in FVC-wet of 282 ml. and 283 ml. in TLC-wet which was statistically significant ($p < .01$).

Table 4. Scheffé post hoc analysis of lung volumes between methods and sex.

Comparison*	Methods	Sex	F Ratio	Level of Significance
FVC	FVC-D vs FVC-W	M	17.13	.01
	FVC-D vs FVC-W	F	9.70	.01
	FVC-D vs FVC-W	M+F	25.70	.01
TLC	TLC-D vs TLC-W	M	17.07	.01
	TLC-D vs TLC-W	F	9.65	.01
	TLC-D vs TLC-W	M+F	25.60	.01

*df $_{1,95}$

The lung volume decreases observed with immersion were similar to those documented in other studies (Hamilton & Mayo, 1944; Carey et al., 1956; Jarrett, 1965; Agostoni et al., 1966; Craig & Ware, 1967; Hong et al., 1969; Bondi et al., 1976; Prefaut et al., 1976; Girandola et al.,

1977; Robertson et al., 1978). These studies have concluded that two factors decrease TLC and FVC when measured while the individual is immersed in water up to the neck. The first factor is that of the hydrostatic pressure gradient which counteracts the force of inspiration by compressing the chest wall and displacing the diaphragm toward the head. The second influencing factor involves the redistribution of blood into the thorax due to the compressive effect of the water on the blood vessels in the extremities. The hydrostatic pressure of 20 cm H_2O applied to the chest when sitting in neck deep water decreases TLC and FVC (Jarrett, 1965; Agostoni et al., 1966). This pressure limits the ability to perform a maximal inhalation necessary in measuring FVC.

In addition to these findings, Craig and Ware (1967) also observed that this pressure was ineffective in increasing maximal exhalation as there was no significant change in RV on land and in water. The blood shift reduces these lung volumes by decreasing lung compliance due to pulmonary engorgement of blood replacing air in the thorax (Hamilton & Mayo, 1944; Agostoni et al., 1966; Hong et al., 1969; Dahlback & Lundgren, 1972). The 5% and 6% reduction in FVC for women and men, respectively, falls in the 1-9% range reported in the literature (Hamilton & Mayo, 1944; Carey et al., 1956; Agostoni et al., 1966; Craig & Ware, 1967; Hong et al., 1969; Dahlback & Lundgren, 1972; Robertson et al., 1978).

It is interesting to note that the effect of immersion on lung volumes was greatest in the males who had the larger lung volumes (see Table 2). This observation agrees with findings of Welch and Crisp

(1958) who also reported that hydrostatic pressure had greater effect on larger lung volumes. It could be concluded that hydrostatic pressure varies on different thoracic volumes. This indicates that the larger amount of air in the lungs of the males may be more susceptible to compression than the smaller amount of air in the lungs of the female. The differences here are relevant when addressing the issue of appropriate measurement of TLC as applied to the technique of HW.

Body Density and Percent Body Fat Measurements

The means and standard deviations of body density and percent body fat for all subjects are reported in Table 5. These measurements were taken by the method of HW at RV, TLC-dry and TLC-wet. Comparison of these methods were chosen to find a method of HW equivocal to the commonly used RV method.

Comparisons of body density and percent body fat for all groups are presented in Table 5 and Appendix D. The method of HW at TLC-dry displayed a higher body density ($\bar{x}$ = 1.0680) thus lower percent body fat ($\bar{x}$ = 13.83) than the other two methods in all subject groups combined. Body density was slightly lower ($\bar{x}$ = 1.0633) and percent body fat was higher ($\bar{x}$ = 15.70) by HW at TLC-wet in all subjects combined. The remaining method of HW at RV produced the lowest body density ($\bar{x}$ = 1.0544) and highest body fat ($\bar{x}$ = 17.47) in all subject groups combined.

An analysis of variance was performed on these data to determine what, if any, of these differences were significant (see Table 6). The levels of significance were similar to those obtained with the lung

Table 5. Means and standard deviations for body density and percent body fat measurements.

Subject Group	Sex	N	Body Density (gm/cc) @RV	Body Density (gm/cc) @TLC-dry	Body Density (gm/cc) @TLC-wet	Percent Body Fat @RV	Percent Body Fat @TLC-dry	Percent Body Fat @TLC-wet
Competitive Swimmers	F	25	1.0433 0.011	1.0512 0.011	1.0467 0.011	23.88 4.776	20.60 4.592	22.47 4.620
Noncompetitive Swimmers	F	31	1.0536 0.013	1.0608 0.014	1.0570 0.014	19.63 5.488	16.69 5.730	18.22 5.641
Total Females	F	56	1.0490 0.013	1.0565 0.014	1.0524 0.014	21.53 5.562	18.44 5.562	20.12 5.588
Competitive Swimmers	M	19	1.0699 0.010	1.0812 0.009	1.0761 0.009	12.98 3.893	8.50 3.520	10.50 3.538
Noncompetitive Swimmers	M	24	1.0735 0.013	1.0844 0.013	1.0787 0.013	11.56 5.317	7.28 5.188	9.51 5.221
Total Males	M	43	1.0719 0.012	1.0830 0.011	1.0776 0.011	12.19 4.742	7.82 4.519	9.95 4.532
Total Combined	M+F	99	1.0590 0.017	1.0680 0.018	1.0633 0.018	17.47 6.976	13.83 7.354	15.70 7.210

volume measurements. There were no significant differences ($p > .05$) between sex and subject group, method and subject group or method, subject group and sex. The non-significance between group and method can indicate that noncompetitive and competitive swimmers performed methods with equal ability. As expected, significant differences were found in body density and percent body fat between subject groups ($p < .01$) and sexes ($p < .001$). Most relevant to the purpose of this study was the demonstration of significant difference between methods of hydrostatic weighing and sex in calculating body density and percent body fat ($p < .001$).

Table 6. Statistical analysis of variance for body density and percent body fat.

Variable	Comparison	df	F Ratio	Level of Significance
Body Density	Competitive vs Noncompetitive	1,95	7.14	.01
	Male vs Female	1,95	104.13	.001
	Sex vs Group	1,95	1.96	NS
	Method vs Group	2,95	0.56	NS
	Method vs Sex	2,95	18.56	.001
	Method vs Group vs Sex	2,95	0.79	NS
Percent Body Fat	Competitive vs Noncompetitive	1,95	7.10	.01
	Male vs Female	1,95	103.12	.001
	Sex vs Group	1,95	2.13	NS
	Method vs Group	2,95	0.75	NS
	Method vs Sex	2,95	14.56	.001
	Method vs Group vs Sex	2,95	0.80	NS

Further analysis of methods and sex by a Scheffe' post hoc test (see Tables 7 & 8) determined where the significance lay. Results show that there was a significant difference ($p < .01$) between HW at RV and HW at TLC-dry in calculating male and female body density and percent body fat. Body density for males was significantly higher ($\bar{x}$ difference = 0.0111) and percent body fat significantly lower ($\bar{x}$ difference = 4.37%) with HW at TLC-dry. Body density for females was also significantly higher ($\bar{x}$ difference = 0.0075) and percent body fat significantly lower ($\bar{x}$ difference = 3.09%). These results are in agreement with the recent study performed by Weltman and Katch (1981). The variation between methods and sexes may be explained by the hydrostatic effect on the lungs. Since FVC was measured on land, the observed differences in body density and percent body fat may be due to the overestimation of TLC at the time of weighing (Welch & Crisp, 1958; Weltman & Katch, 1981). Less air was actually in the lungs when immersed as compared to on land (males $\bar{x}$ TLC-wet = 6.796 L., $\bar{x}$ TLC-dry = 7.146 L.; females $\bar{x}$ TLC-wet = 5.085 L., $\bar{x}$ TLC-dry = 5.316 L.). The larger lung volumes were affected to a greater extent. The 5% and 4% overestimated volume of air in the males and females, respectively, was sufficient to influence body density and percent body fat calculations causing significant differences in HW at RV and HW at TLC-dry.

In combining data from all subjects, the post hoc analysis revealed similar findings. Body density and percent body fat measurements were statistically different ($p < .01$) between HW at RV and HW at TLC-dry.

Table 7. Scheffé post hoc analysis of body density between methods and sex.

Comparison	HW Method	Sex	F Ratio	Level of Significance
Body Density	RV vs TLC-D	M	33.01	.01
	RV vs TLC-W	M	8.56	.05
	TLC-D vs TLC-W	M	7.95	.05
	RV vs TLC-D	F	19.69	.01
	RV vs TLC-W	F	4.05	NS
	TLC-D vs TLC-W	F	5.88	NS
	RV vs TLC-D	M+F	50.12	.01
	RV vs TLC-W	M+F	11.44	.01
	TLC-D vs TLC-W	M+F	13.67	.01

$df_{2,95}$: F @ .05 = 6.20, @ .01 = 9.68

Table 8. Scheffé post hoc analysis of percent body fat between methods and sex.

Comparison	HW Method	Sex	F Ratio	Level of Significance
% Body Fat	RV vs TLC-D	M	41.04	.01
	RV vs TLC-W	M	10.77	.01
	TLC-D vs TLC-W	M	9.76	.01
	RV vs TLC-D	F	26.80	.01
	RV vs TLC-W	F	5.59	NS
	TLC-D vs TLC-W	F	7.92	.05
	RV vs TLC-D	M+F	65.73	.01
	RV vs TLC-W	M+F	15.54	.01
	TLC-D vs TLC-W	M+F	17.35	.01

$df_{2,95}$: F @ .05 = 6.20, @ .01 = 9.68

The Scheffe post hoc analyses of this study (see Tables 7 & 8) revealed that there was no statistical difference between HW at RV and HW at TLC-wet in estimating body density and percent body fat in females ($p > .05$). By measuring FVC-wet and combining it with RV, a true representation of TLC while immersed was established. Therefore, all air in the lungs was recognized during immersion.

A statistical difference was found between HW at RV and HW at TLC-wet in estimating body density ($p < .05$) and percent body fat ($p < .01$) in males. Percent body fat was consistently higher using HW at RV ($\bar{x}$ = 12.19) than at TLC-wet ($\bar{x}$ = 9.95). These differences may indicate significant air trapping increasing RV during HW at RV as suggested by Dahlback and Lundgren (1972) and Girandola et al. (1977). This air trapping may have been eliminated at the larger lung capacity of TLC during immersion. These observations were also made by Dahlback and Lundgren (1972). The possible underestimation of RV when immersed would account for the higher percent body fat calculated from HW at RV. This unaccounted volume of air caused the body to be more buoyant yielding an inaccurate higher body fat. The use of TLC-wet may, therefore, increase the accuracy of HW.

The different levels of significance found in HW at RV and HW at TLC between men and women may be due to varying degrees in air trapping. It has been shown that there is a large range in closing volumes for individuals of approximately the same age (Burki, Barker & Nicholson, 1975). This factor affects air trapping and RV. It appears that the males in this study may have had more air trapping during HW at RV than the females causing the significant difference in methods.

The review of literature does not make reference to HW at TLC-wet as this was recently suggested as the possible method of choice by Weltman and Katch (1981). Several reasons may substantiate HW at TLC-wet as the method of choice. Agreement on RV changes during immersion have not been uniform, as outlined in Chapter II. Observations have been made that pulmonary vascular congestion results in air trapping and decreased lung compliance at low lung volumes in water (Dahlback & Lundgren, 1972; Girandola et al., 1977). These factors would increase RV in water at maximal expiration. Residual volume measurements in water have been inaccurate (Dahlback & Lundgren, 1972; Bondi et al., 1976; Robertson et al., 1978), and measurements on land may be an underestimation of RV in water. An incorrect RV measurement may significantly alter the calculations of body density and percent body fat by HW. An underestimation of RV at the time of weighing may explain the highest percent body fat of all methods tested in this study.

The problem of air trapping during immersion may be reduced or eliminated with large lung volumes (Dahlback & Lundgren, 1972; Thomas & Etheridge, 1980). Incorporating this observation in reference to HW techniques, TLC-wet may be the method of choice. When combining all subjects, statistical analysis indicates significant differences between HW at RV and HW at TLC-wet. It should be noted that percent body fat was consistently higher using HW at RV ($\bar{x}$ overall % BF = 17.47). This may indicate an air trapping which was eliminated uring HW at TLC-wet ($\bar{x}$ overall % BF = 15.70).

The mean differences in percent body fat for women were 3.09% between HW at RV and HW at TLC-dry; 1.41% between HW at RV and HW at

TLC-wet. Males produced mean differences of 4.37% between HW at RV and HW at TLC-dry; 2.24% between HW at RV and HW at TLC-wet. Overall mean differences of all subjects combined were 3.64% between HW at RV and HW at TLC-dry; 1.77% between HW at RV and HW at TLC-wet. These observations are not within the ± 4% error associated with predicting body fat by HW (Siri, 1961). Hydrostatic weighing at TLC-wet would be preferred over TLC-dry as the percentage of error would be less.

Although differences in body density and percent body fat may be statistically significant between HW at RV and HW at TLC-wet, observation in performance of methods, reported below, may also support clinical application of HW at TLC-wet. At this point, subject preference to methods also reveals HW at TLC as the method of choice. Data tabulation concerning subject preference of methods has been presented below.

Preference of Methods

Data referring to the responses of HW method preferred are recorded in Table 9. A Chi Square was used in the analysis of collected data. Combined sexes into subject groups shows similarities in method preference. Thirty-one of the noncompetitive swimmers (N = 55) and 24 of the competitive swimmers (N = 44) preferred HW at TLC. The choice of HW at TLC was significant ($p < .05$) over preference of HW at RV and over the option of no preference in regards to method. These data also indicate HW at TLC to be the method of choice by all subjects combined ($p < .05$). These subjects indicated that they felt more comfortable and could hold their breath longer at TLC.

Table 9. Chi Square analysis of method preference.

Subject Group	N	HW at RV	HW at TLC	None
Female Noncompetitive Swimmers	31	6	17*	8
Male Noncompetitive Swimmers	24	6	14*	4
Total Noncompetitive Swimmers	55	12	31*	12
Female Competitive Swimmers	25	5	16*	4
Male Competitive Swimmers	19	4	8	7
Total Competitive Swimmers	44	9	24*	11
Total Combined	99	21	55*	23

*$p < .05$

These data are in agreement with observations made by Thomas and Etheridge (1980), and Weltman and Katch (1981). Hydrostatic weighing at TLC offers several advantages over HW at RV. Brozek et al. (1949) reported a reduced psychological effect when the subjects' lungs were fully inflated. The noncompetitive swimmers, who may not be comfortable in a water environment, appeared to be more at ease during weighing at TLC as compared to RV. This enabled the subject to remain under water in a more relaxed state. The weighing scale fluctuation was reduced allowing the investigator to obtain a weight reading at stabilization in less time.

Hydrostatic weighing at TLC-wet may be most applicable to adult fitness evaluations such as those performed in fitness programs. The participants in these programs are often older and may have increased pulmonary air trapping with HW at RV (Anthonisen et al., 1969). These

people are often unable to successfully perform the required maximal exhalation while submerged underwater mandated with HW at RV.

CHAPTER V

CONCLUSIONS

Summary

The purpose of this study was to determine if HW at TLC was equivocal to the method of HW at RV. It was also the purpose to determine the appropriate measurement of TLC-dry or wet in application to the calculation of body density. All subjects were underwater weighed at lung volumes of RV and TLC. Three body densities and percent body fats were calculated for each subject by applying lung measurements of RV, TLC-dry and TLC-wet. Subjects noted HW method of choice; at RV, TLC or no preference. Statistical analyses were then applied to determine if there were significant differences between HW methods or lung volume measurements performed in or out of the water.

Conclusions

The results of this study indicated the following conclusions:

1. Competitive swimmers had significantly larger FVC and TLC measurements than noncompetitive swimmers.

2. Males had significantly larger FVC and TLC measurements than females.

3. All males and females produced significantly smaller FVC and TLC when measured wet compared to dry.

4. There were no significant differences in lung volume or capacity measurements of competitive and noncompetitive swimmers.

5. Males' FVC and TLC measurements were decreased more than the females' FVC and TLC measurements when immersed. This would indicate that immersion has the greatest effect on larger lung volumes.

6. Competitive swimmers had significantly larger percent body fat and smaller body density measurements than the noncompetitive swimmers. Similar results were observed comparing all females to all males.

7. Hydrostatic weighing at RV produced the highest percent body fat in all subgroups. It was concluded that RV while immersed may have been underestimated as pulmonary air trapping may increase with immersion.

8. Hydrostatic weighing at TLC-dry produced the lowest percent body fat in all subgroups. It was concluded that TLC was overestimated as the FVC component was significantly decreased in all subgroups when measured immersed. This resulted in significant differences between HW at RV and HW at TLC-dry in calculating body density and percent body fat for all subgroups.

9. Hydrostatic weighing at TLC-wet was not statistically different from HW at RV in body density and percent body fat calculations in females. In measuring FVC-wet and combining it with RV, a true representation of TLC while immersed was established.

10. Hydrostatic weighing at TLC-wet was statistically different from HW at RV in body density and percent body fat calculations in males. The significance here may be due to varying degrees of air trapping in the lungs at RV level during HW at RV. The underestimated RV in HW at RV would result in an inaccurate high percent body fat.

11. Hydrostatic weighing is not equivocal at RV, TLC-dry and TLC-wet. Results of percent body fat were not within the ± 4% error of prediction associated with HW.

12. Although a significant difference exists between HW at RV and HW at TLC-wet, the mean difference in percent body fat for all subjects combined was only 1.77%. Hydrostatic weighing at TLC-wet may be most accurate in percent body fat determination. Previous research supports conclusion that pulmonary air trapping was reduced or eliminated and TLC was accurately represented during HW at TLC-wet.

13. Hydrostatic weighing at TLC was significantly preferred over HW at RV by both competitive and noncompetitive swimmers. Subjects indicated that immersion at TLC was more comfortable than at RV.

14. Since pulmonary air trapping is more prevalent in older age, HW at TLC-wet appears to be indicated in older adults.

15. This researcher made observations that subjects were more relaxed during submersion and there was less scale fluctuation during HW at TLC. It can be concluded that HW at TLC is performed better than HW at RV by the subjects. The tester is able to obtain a more accurate weight recording from the scale during HW at TLC. It is suggested, therefore, that HW at TLC-wet may be clinically applied and is indicated especially with individuals who are not well adapted to a water environment.

Recommendations

The following suggestions are made in reference to future studies:

1. As the differences between HW at RV, HW at TLC-dry and HW at TLC-wet became less significant in the smaller lung volumes of the females of this study, it would be interesting to perform the same study using children.

2. Further research is needed to clarify the hydrostatic effect on closing volume and residual volume.

3. Since pulmonary air trapping is more prevalent in older age, a similar study should be performed comparing HW at RV, TLC-dry and TLC-wet in older populations.

4. Since the body plethysmograph is more sensitive to air trapping, RV determination by body plethysmograph and nitrogen washout should be compared in relation to HW.

REFERENCES CITED

Agostoni, E., Gurtner, G., Torri, G., & Rahn, H. Respiratory mechanics during submersion and negative pressure breathing. Journal of Applied Physiology, 1966, 21, 251-258.

Anthonisen, N., Dannon, J., Robertson, P., & Ross, W. Airway closure as a function of age. Respiratory Physiology, 1969, 8, 58-65.

Bedwell, G., Marshall, R., DeBois, A. & Harris, J. Measurement of the volume of gas in the gastro-intestinal tract. Values in normal subjects and ambulatory patients. Journal of Clinical Investigation, 1956, 35, 336-345.

Behnke, A. R. Quantitative assessment of body build. Journal of Applied Physiology, 1961, 16, 960-968.

Bondi, K. R., Young, J. M. Bennett, R. M., & Bradley, M. E. Closing volumes in man immersed to the neck in water. Journal of Applied Physiology, 1976, 40(5), 736-740.

Brozek, J., Henschel, A., & Keys, A. Effect of submersion in water on the volume of residual air in man. Journal of Applied Physiology, 1949, 2, 240-246.

Brozek, J., Grande, F., Anderson, J. T., & Keys, A. Densitometric analysis of body composition: Revision of some quantitative assumptions. Annals New York Academy of Sciences, 1963, 110, 113-140.

Burki, N. K. Spirometry and other pulmonary function tests. The Journal of Family Practice, 1981, 12(1), 119-124.

Burki, N. K., Barker, D. B. & Nicholson, D. P. Variability of the closing volume measurement in normal subjects. American Review of Respiratory Diseases, 1975, 112, 209-212.

Buskirk, E. Underwater weighing and body density: a review of procedures. In J. Brozek and A. Henschel (Eds.), Techniques for measuring body composition, pp. 90-107, Washington, D. C.: National Academy of Sciences - National Research Council, 1961.

Carey, C. R., Scheafer, K. E., & Alvis, H. J. Effect of skin diving on lung volume. Journal of Applied Physiology, 1956, 8, 519-523.

Craig, A. B., & Ware, D. E. Effect of immersion in water on vital capacity and residual volume of the lungs. Journal of Applied Physiology, 1967, 23(4), 423-425.

Cureton, K. J., Hensley, L. D., & Tiburzi, A. Body fatness and performance differences between men and women. Research Quarterly, 1979, 50(3), 333-340.

Dahlback, G. O., & Lundgren, C. E. G. Pulmonary air-trapping induced by water immersion. Aerospace Medicine, 1972, 43(7), 768-771.

Etheridge, G. L., & Thomas, T. R. The effect of body position and water immersion on lung volumes of women. Medicine and Science in Sport, 1978, 10, 61.

Girandola, R. N., Wiswell, R. A., Mohler, J. G., Romero, G. T., & Barnes, W. S. Effects of water immersion on lung volumes: implications for body composition analysis. Journal of Applied Physiology, 1977, 43(3), 276-279.

Goldman, R., & Buskirk, E. Body volume measurement by underwater weighing: Description of a method. In J. Brozek and A. Henschel (Eds.), Techniques for measuring body composition, pp. 78-89, Washington, D. C.: National Academy of Sciences - National Research Council, 1961.

Hamilton, W., & Mayo, J. Changes in the vital capacity when the body is immersed in water. Journal of Applied Physiology, 1944, 141, 51-53.

Hong, S. K., Ting, E. Y., & Rahn, H. Lung volumes at different depths of submersion. Journal of Applied Physiology, 1960, 15, 550-553.

Hong, S. K., Cerretelli, P., Cruz, J. C., & Rahn, H. Mechan.cs of respiration during submersion in water. Journal of Applied Physiology, 1969, 27, 535-538.

Jarrett, A. S. Effect of immersion on intrapulmonary pressure. Journal of Applied Physiology, 1965, 20(6), 1261-1266.

Jensen, D. G. Determination of body density in prepubescent males, age 7-11. Thesis (M. S.), University of Wisconsin-La Crosse, 1979.

Kacmarek, R. M., Dimas, S., & Mack, C. W. The essentials of respiratory therapy. Chicago: Yearbook Medical, 1979.

Karpovich, P. V., & Sinning, W. E. Physiology of muscular activity (7th ed.). Philadelphia: W. B. Saunders, 1971.

Katch, F., Michael, E. D., & Horvath, S. M. Estimation of body volume by underwater weighing: description of a simple method. Journal of Applied Physiology, 1967, 23(5), 811-813.

Keys, A., & Brozek, J. Body fat in adult man. Physiological Reviews, 1953, 33, 245-325.

Kory, R. C., Callahan, R., & Boren, H. G. The veterans administration-army cooperative study of pulmonary function: part 1: clinical spirometry in normal men. American Journal of Medicine, 1961, 30, 243.

Lawther, G. Estimation of underwater residual volume from related measures (Ph.D. dissertation). University Park, Pa.: Pennsylvania State University, 1969.

McBride, J. T., & Wohl, M. E. B. Pulmonary function tests. Pediatric Clinics of North America, 1979, 26(3), 537-551.

Morris, J. F., Koski, A. & Johnson, L. C. Spirometry standards for healthy non-smoking adults. American Review of Respiratory Diseases, 1971, 103, 57.

Prefaut, C., Lupi-H, E., & Anthonisen, N. R. Human lung mechanics during water immersion. Journal of Applied Physiology, 1976, 40(3), 320-323.

Rathburn, E., & Pace, N. Studies on body composition. I. The determination of total body fat by means of the body specific gravity. Journal of Biological Chemistry, 1945, 158, 667-676.

Robertson, C. H., Jr., Engle, C. M., & Bradley, M. E. Lung volumes in man immersed to the neck: dilution and plethysmographic techniques. Journal of Applied Physiology, 1978, 44(5), 679-682.

Sawka, M. N., Weber, H., & Knowlton, R. G. The effect of total body submersion on residual lung volume and body density measurements in man. Ergonomics, 1978, 21(2), 89-94.

Sheen, A., & Sly, R. M. Evaluation of calibration of spirometers. Annals of Allergy, 1980, 45(3), 127-129.

Siri, W. Body composition for fluid spaces and density: Analysis of methods. In J. Brozek and A. Henschel (Eds.), Techniques for measuring body composition, pp. 223-244. Washington, D. C.: National Academy of Sciences - National Research Council, 1961.

Sloan, A. W. Estimation of body fat in young men. Journal of Applied Physiology, 1967, 23, 311-315.

Thomas, T. R., & Etheridge, G. L. Hydrostatic weighing at residual volume and functional residual capacity. Journal of Applied Physiology: Respiratory, Environment, and Exercise Physiology, 1980, 49(1), 157-159.

Welch, B. E., & Crisp, C. E. Effect of the level of expiration on body density measurement. Journal of Applied Physiology, 1958, 12(3), 399-402.

Weltman, A., & Katch, V. Comparison of hydrostatic weighing at residual volume and total lung capacity. Medicine and Science in Sports Exercise, 1981, 13(3), 210-213.

Wilmore, J. H. A simplified method for determination of residual lung volumes. Journal of Applied Physiology, 1969, 27(1), 96-100.

Wilmore, J. H., & Behnke, A. R. Predictability of lean body weight through anthropometric assessment in college men. Journal of Applied Physiology, 1969, 27, 349-355.

Wilmore, J. H., & Behnke, A. R. An anthropometric estimation of body density and lean body weight in young women. American Journal of Clinical Nutrition, 1970, 23, 267-274.

Wilmore, J. H., Vodak, P. A., Parr, R. B., Girandola, R. N., & Billing, J. E. Further simplification of a method for determination of residual lung volume. Medicine and Science in Sports and Exercise, 1980, 12(3), 216-218.

Zuti, W. B., & Corbin, C. B. Physical fitness norms for college freshmen. Research Quarterly, 1977, 48, 499-503.

APPENDIX A

INFORMED CONSENT FORM

Project Title: Comparison of Three Hydrostatic Weighing Methods

Principle Investigators: Joann M. McGarty / N. K. Butts, Ph.D.

1. I have abstained from food and drink for 12 hours prior to testing.

2. My forced vital capacity will be measured by spirometry on land and again when immersed in water to neck level both in the seated position. I am required to inhale maximally and exhale forcefully as much air as possible into a spirometer. Two trials will be necessary.

3. My residual volume will be determined by the nitrogen washout technique. This procedure will require me to rebreathe a bag of pure oxygen for five to ten breaths. I will also be asked to inhale maximally and then forcefully exhale into the mouthpiece attached to the nitrogen analyzer.

4. Wearing appropriate swimming apparel, I will be weighed on land and then by two methods of hydrostatic weighing. One method requires me to submerge beneath the surface of the water after forcefully expelling as much air as possible from the lungs. This process may be repeated three to ten times. The second method requires me to inhale maximally and hold my breath underwater. This method will be repeated in three trials.

5. The tester will calculate the percent of body fat from an established equation.

6. I will respond to a question to the best of my ability concerning preference of one hydrostatic weighing technique in relation to the other.

7. There may be some discomfort in breath holding underwater. Some risk factors which rarely occur involve possible accident, drowning and infection.

8. I will benefit from the hydrostatic weighing by knowing my percent body fat. This may reflect the effectiveness of a present exercise program practiced aimed at reducing body fat or imply the need for one to be initiated.

9. The Principle Investigator will answer any and all questions concerning procedures, risks or benefits.

I, _____, being of sound mind and
(Print Name)
_____ years of age, do hereby consent to, authorize and request the person named above (and her co-workers, agents, and employees) to undertake and perform on me the proposed procedures.

I have read the above document, and I have been fully advised of the nature of the procedure and the possible risks and complications I hereby assume voluntarily.

I hereby acknowledge that no representations, warranties, guarantees or assurances of any kind pertaining to the procedures have been made to me by the University of Wisconsin-La Crosse, the officers, administration, employees or by anyone acting on behalf of any of them.

I understand that I may withdraw from the program at any time.

Signed at _____ this _____
day of _____, 19___, in the presence of the witnesses whose signatures appear below opposite my signature.

WITNESSED BY:

_____ _____
(Subject)

_____

APPENDIX B

RESIDUAL VOLUME DATA SHEET

NAME _____ AGE _____
First Last

	Trial 1.	Trial 2.
Initial Volume of O_2 (VO_2):	_____	_____
$\%N_2$ (Impurity) (IN_2):	_____	_____
$\%N_2$ (Alveolar) (AN_2):	_____	_____
$\%N_2$ (Equilibrium) Range:	_____	_____
$\%N_2$ (Equil.) (EN_2):	_____	_____
$\%N_2$ (Final) (FN_2):	_____	_____
Dead Space (DS):	_____	_____

$$\text{RESIDUAL VOLUME} = \frac{VO_2\ (EN_2 - IN_2)}{(AN_2 - FN_2)} - DS$$

$$= \_\_\_\_\_ \text{ L.}$$

APPENDIX C

HYDROSTATIC WEIGHING AND LUNG VOLUME DATA SHEET

NAME _____

FVC-dry: _____ L. RV: _____ L.

FVC-wet: _____ L.

TLC-dry: _____ L.

TLC-wet: _____ L.

Immersion Tank Temp. _____ ^{o} C.

Density of Water (D_W) 0._____.

Mass in Air (M_A) _____kg.

Mass in Water (M_X) _____kg.

Mass of Weighing Apparatus (M_Y) _____kg.
(in water)

Mass of Water (M_W) = $M_X - M_Y$ = _____kg.

Air in G.I. Tract = 100 ml. = 0.1 L.

Body Density (D_B) = $\dfrac{M_A}{\dfrac{M_A - M_W}{D_W} - RV - 0.1\ L.}$ = _____ gm/cc.

% Body Fat = $\dfrac{4.570}{D_B} - 4.142 \times 100$ = _____%

TLC Trials				RV Trials			
1.	_____	6.	_____	1.	_____	6.	_____
2.	_____	7.	_____	2.	_____	7.	_____
3.	_____	8.	_____	3.	_____	8.	_____
4.	_____	9.	_____	4.	_____	9.	_____
5.	_____	10.	_____	5.	_____	10.	_____

APPENDIX D

RESULTS OF SCHEFFÉ POST HOC FOR HW AND LUNG VOLUME METHODS

Variable	ANOVA Significance	Significant Comparisons
Body Density	Methods X Sex	TLC-DM > RV-M, TLC-WM, RV-F, TLC-DF, TLC-WF TLC-WM > RV-M, RV-F, TLC-DF, TLC-WF RV-M > RV-F, TLC-DF, TLC-WF TLC-DF > RV-F, TLC-WF TLC-WF > RV-F
Percent Body Fat	Methods X Sex	RV-F > TLC-DF, RV-M, TLC-WF, TLC-DM, TLC-WM TLC-WF > TLC-DF, RV-M, TLC-DM, TLC-WM TLC-DF > RV-M, TLC-DM, TLC-Wn RV-M > TLC-DM, TLC-WM TLC-WM > TLC-DM
FVC	Methods X Sex	FVC-DM > FVC-WM > FVC-DF > FVC-WF
TLC	Methods X Sex	TLC-DM > TLC-WM > TLC-DF > TLC-WF

TLC-DM = total lung capacity-dry, males

TLC-WM = total lung capacity-wet, males

TLC-DF = total lung capacity-dry, females

TLC-WF = total lung capacity-wet, females

RV-M = residual volume, males

RV-F = residual volume, females

FVC-DM = forced vital capacity-dry, males

FVC-WM = forced vital capacity-wet, males

FVC-DF = forced vital capacity-dry, females

FVC-WF = forced vital capacity-wet, females